ICS
BUILDING TRADES
HANDBOOK

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BUILDING TRADES HANDBOOK

366 pages, illustrated

A convenient reference book of building construction treating on Mathematics, Geometrical Drawing, Structural Design, Concrete, Stonework, Brickwork, Terra-Cotta, Masonry, Fireproofing, Carpentry, Millwork, Plastering, Roofing and Estimating of use to persons connected in any way with the building trades. Every householder, in particular, will find this handbook a useful, convenient reference.

Contents: Mathematics: Signs used in Calculation, Fractions, Involution, Evolution, Table of Powers, Roots and Reciprocals, Decimal Equivalents of 64ths., Weights and Measures, The Metric System, Formulas, Mensuration; Geometrical Drawing: Problems, Laying out Angles, Structural Design: Specific Gravity, Loads on Structures, Strength of Materials, Composition and Resolution of Forces, Properties of Sections, Radius of Gyration, Beams, Design of Beams, Columns, Roof Trusses; Masonry Construction: Concrete, Stone, Brick Masonry, Architectural Terra Cotta, Hollow Tile Construction; Reinforced Concrete: Important Properties, Reinforced-Concrete Beams, Reinforced-Concrete Columns; Details of Buildings: Foundations; Fireproofing: Construction with Hollow Tile, Arches, Chimneys and Fireplaces; Plastering: Furring and Grounds, Lathing, Plaster; Carpentry and Millwork: Woods used in Building, Wood Framing, Hangers, Caps, and Anchors, Provision for Shrinkage, Roof Framing, Windows, Glass, Outside Finish, Inside Finish; Steel Square: Use in Roof Framing; Roofing: Built-up Roofs, Sheet Metal Roofs, Slate Roofs, Tile Roofs, Asbestos Shingles, Canvas Roofs; Estimating: Approximate and General Estimates, Masonry, Brickwork, Carpentry, Joinery, or Millwork, Plastering, Painting and Papering, Miscellaneous Estimates; Index.

THE BUILDING TRADES HANDBOOK

A CONVENIENT REFERENCE BOOK
OF BUILDING CONSTRUCTION

TREATING OF

Mathematics, Geometrical Drawing,
Structural Design, Concrete, Stonework,
Brickwork, Terra-Cotta, Masonry, Fire-
proofing, Carpentry, Millwork, Plastering,
Roofing, Estimating

BY

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PREFACE

This handbook is intended for the use of architects, draftsmen, and other persons who are interested in the building trades, especially masonry, carpentry, structural design, and roofing. In the first part of the book is given a brief, but comprehensive, treatment of elementary mathematics and geometrical drawing. This is followed by a section on structural design, which includes dead and live loads, strength of materials, properties of sections, design of beams and columns of steel and wood, and analysis of stresses in roof trusses.

The next section of the book deals with masonry construction and describes the essential features of concrete, stone masonry, brick masonry, architectural terra cotta, and hollow tile construction. The principles of reinforced-concrete design are then discussed, and this discussion is followed by a description of details of buildings, including foundations, fireproofing, arches, and chimneys and fireplaces.

The remainder of the book is devoted to the work of the plasterer, the carpenter, and the roofer. For each trade, there is presented a discussion of the materials used and the methods employed in preparing and placing the materials. In the section on Carpentry and Millwork are described several types of framing for buildings, details of window construction, and both outside and inside finish. The book also contains a section on the steel square and a section on estimating.

This handbook has been prepared by technical writers on the staff of the International Correspondence Schools.

THE BUILDING TRADES HANDBOOK

MATHEMATICS

SIGNS USED IN CALCULATION

$+$ *Plus*, indicates *addition;* thus, $10+5$ is 15.

$-$ *Minus*, indicates *subtraction;* thus, $10-5$ is 5.

$\times$ *Multiplied by*, indicates *multiplication;* thus, 10×5 is 50.

$\div$ *Divided by*, indicates *division;* thus, $10\div5$ is 2.

$=$ *Equal to*, indicates *equality;* thus, 12 in. = 1 ft.

Parentheses ( ), *brackets* [ ], and *braces* { } have the same meaning, and signify that the operations indicated within them are to be performed first. If more than one is used, that indicated in the inner one is to be effected first. Thus, in the expression $5(7-2)$, the subtraction is to be made before multiplying by 5. Again, in the expression $\frac{1}{2}\left[a+\left(b-\frac{c}{4}\right)\right]$, the subtraction indicated within the parentheses is made first; the remainder is added to a, and one-half the sum found.

The *vinculum* —— is used for the same purpose as parentheses, but chiefly in connection with the sign $\sqrt{}$; thus, $\sqrt{\quad}$.

The *decimal point* . is placed in a number containing decimals, to fix the value of the number; thus, 12.5 is 12 and $\frac{5}{10}$; 1.25 is 1 and $\frac{25}{100}$; etc.

The *exponent* is a small figure placed to the right and a little above a number,—it means the number is to be raised to the power indicated by the small figure; thus, $8^2=8\times8=64$.

The *radical sign* $\sqrt{\ }$, means that some root of the expression under it is to be found. The vinculum is generallly used in connection with this sign and extends over the number affected by the radical sign. If used without a small index figure, it means square root; thus, $\sqrt{64}=8$. $\sqrt[3]{\quad}$ $\sqrt[4]{\quad}$ means that the *cube* root or the *fourth* root is to be found, the index figure indicating the root; thus, $\sqrt[3]{27}=3$.

The signs : : : : indicate proportion; thus, 3 : 4 : : 6 : 8 is read 3 *is to* 4 *as* 6 *is to* 8. Instead of the : : sign, the equality sign = is *often* substituted; thus, 3 : 4 = 6 : 8.

The signs ° ′ ″ mean degrees, minutes, and seconds; as 60° 15′ 15″, which is read *60 degrees, 15 minutes, 15 seconds.*

The signs ′ ″ also mean feet and inches; thus, 7′ 6″ is read *7 feet 6 inches.*

The symbol π (read *pi*) means the ratio of the circumference of a circle to the diameter and $=3.1416$.

The symbol Σ (read *sigma*) means *summation;* thus, $\Sigma(a+b)$ means that there are several values for both a and b, and that the sum of all is to be found.

FRACTIONS

COMMON FRACTIONS

The *numerator* of a fraction is the number above the bar; and the *denominator* is the number beneath it; thus, in the fraction $\frac{3}{4}$, 3 is the numerator and 4 is the denominator. Two or more fractions having the same denominator are said to have a *common* denominator.

By *reducing fractions to a common denominator* is meant finding such a denominator as will contain each of the given denominators without a remainder, and multiplying each numerator by the number of times its denominator is contained in the common denominator. Thus, the fractions $\frac{1}{4}$, $\frac{7}{8}$, and $\frac{9}{16}$ have, as a common denominator, 16; then $\frac{1}{4}=\frac{4}{16}$; $\frac{7}{8}=\frac{14}{16}$; $\frac{9}{16}=\frac{9}{16}$.

By *reducing a fraction to its lowest terms* is meant dividing both numerator and denominator by the greatest number that each will contain without a remainder; for example, in $\frac{14}{16}$, the greatest number that will thus divide 14 and 16 is 2; so that $\frac{14 \div 2}{16 \div 2} = \frac{7}{8}$, which is $\frac{14}{16}$ reduced to the lowest terms.

A *mixed number* is one consisting of a whole number and a fraction, as $7\frac{3}{8}$.

An *improper fraction* is one in which the numerator is equal to, or greater than, the denominator, as $\frac{17}{8}$. This is reduced to a mixed number by dividing 17 by 8, giving $2\frac{1}{8}$. If the numerator is less than the denominator, the fraction is termed *proper*. A mixed number is reduced to a fraction by multiplying the whole number by the denominator, adding the numerator, and placing the sum over the denominator; thus, $1\frac{7}{8} = \frac{(1 \times 8) + 7}{8} = \frac{15}{8}$.

Addition of Fractions or Mixed Numbers.—If fractions only are to be added, reduce them to a common denominator, and place the sum of the numerators over the common denominator. If mixed numbers are to be added, add the sum of the fractions to that of the whole numbers; thus, $1\frac{7}{8} + 2\frac{1}{4} = (1+2) + (\frac{7}{8} + \frac{2}{8}) = 4\frac{1}{8}$.

Subtraction of Fractions or Mixed Numbers.—If there are fractions only, reduce them to a common denominator, take less from greater, and reduce result; as, $\frac{7}{8}$ in. $- \frac{9}{16}$ in. $= \frac{14-9}{16} = \frac{5}{16}$ in.

If there are mixed numbers, subtract fractions and whole numbers separately, placing remainders beside one another; thus, $3\frac{7}{8}$ in. $- 2\frac{1}{4}$ in. $= (3-2) + (\frac{7}{8} - \frac{2}{8}) = 1\frac{5}{8}$ in. With fractions like the following, proceed as indicated: $3\frac{7}{16}$ in. $- 1\frac{13}{16}$ in. $= (2 + \frac{16}{16} + \frac{7}{16}) - 1\frac{13}{16} = 2\frac{23}{16} - 1\frac{13}{16} = 1\frac{10}{16} = 1\frac{5}{8}$ in.; 7 in. $- 4\frac{3}{4}$ in. $= (6 + \frac{4}{4}) - 4\frac{3}{4} = 2\frac{1}{4}$ in.

Multiplication of Fractions.—Multiply the numerators together, and likewise the denominators, and divide the former by the latter; thus, $\frac{1}{2}$ in. $\times \frac{3}{4}$ in. $\times \frac{5}{8}$ in. $= \frac{1 \times 3 \times 5}{2 \times 4 \times 8} = \frac{15}{64}$ cu. in.

If mixed numbers are to be multiplied, reduce to fractions, and proceed as shown; thus, $1\frac{1}{2}$ in. $\times 3\frac{1}{4}$ in. $= \frac{3}{2} \times \frac{13}{4} = \frac{39}{8} = 4\frac{7}{8}$ sq. in.

Division of Fractions.—Invert the divisor (exchange places of numerator and denominator) and multiply the dividend by it, reducing the result, if necessary; thus, $\frac{7}{8} \div \frac{3}{4} = \frac{7}{8} \times \frac{4}{3} = \frac{28}{24} = \frac{7}{6} = 1\frac{1}{6}$. If there are mixed numbers, reduce them to fractions, and divide as shown; thus, $1\frac{5}{8} \div 3\frac{1}{4} = \frac{13}{8} \div \frac{13}{4}$, or $\frac{13}{8} \times \frac{4}{13} = \frac{52}{104} = \frac{1}{2}$.

DECIMAL FRACTIONS

In decimals, whole numbers are divided into tenths, hundredths, etc.; thus, $\frac{1}{10}$ is written .1; .08 is read $\frac{8}{100}$, the value of the number being indicated by the position of the decimal point; that is, one figure after the decimal point is read as so many tenths; two figures as so many hundredths; etc. Moving the decimal point to the right multiplies the number by 10 for every place the point is moved; moving it to the left divides the number by 10 for every place the point is moved. Thus, in 125.78 (read 125 and $\frac{78}{100}$), if the decimal point is moved one place to the right, the result is 1,257.8, which is 10 times the first number; or, if the point is moved to the left one place, the result is 12.578 which is $\frac{1}{10}$ the first number, moving the point being equivalent to dividing 125.78 by 10.

Annexing a cipher to the right of a decimal does not change its value; but each cipher inserted between the decimal point and the decimal divides the decimal by 10; thus, in 125.078, the decimal part is $\frac{1}{10}$ of .78.

Addition of Decimals.—Place the numbers so that the decimal points are in a vertical line, and add in the ordinary way, placing the decimal point of the sum under the other points.

$$\begin{array}{r} 101.257 \\ 12.965 \\ 43.005 \\ 920.600 \\ \hline 1{,}077.827 \end{array}$$

Subtraction of Decimals.—Place the number to be subtracted with its decimal point under that of the other number, and subtract.

$$\begin{array}{r} 917.678 \\ 482.710 \\ \hline 434.968 \end{array}$$

Multiplication of Decimals.—Multiply in the ordinary way, and point off from the right of the result as many figures as there are figures to the right of the decimal points in both numbers multiplied. Thus, as there are three figures to the right of the points, point off that many in the result. If either number contains no decimal, point off as many places in the product as there are decimal places in the other number.

$$\begin{array}{r} 21.72 \\ 34.1 \\ \hline 2172 \\ 8688 \\ 6516 \\ \hline 740.652 \end{array}$$

If a result has not as many figures as the sum of the decimal places in the numbers multiplied, enough ciphers must be prefixed to the figures to make up the required number of places, and the decimal point placed before the ciphers. Thus, in $.002\times.002$, the product of $2\times2=4$; but there are three places in each number; hence, the product must have six places, and five ciphers must be prefixed to the 4, which gives .000004.

Division of Decimals.—Divide in the usual way. If the dividend has more decimal places than the divisor, point off, from the right of the quotient, the number of places in excess. If it has less than the divisor, annex as many ciphers to the decimal as are necessary to give the dividend as many places as there are in the divisor; the quotient will then have no decimal places. For example, $\frac{25.75}{2.5}=10.3$; $\frac{82.5}{2.75}=\frac{82.50}{2.75}=30$; $\frac{7.5}{2.5}=3$.

To carry a division to any number of decimal places, annex ciphers to the dividend, and divide, until the desired number of figures in the quotient is reached, which are pointed off as just shown. Thus, $36.5\div18.1$ to three decimal places $=\frac{36.5000}{18.1}=2.016+$. (The sign + thus placed after a number indicates that the exact result would be more than the one given if the division were carried further.)

Reducing a Decimal to a Common Fraction.—Use the significant figure, or figures, of the decimal as the numerator; and for the denominator put 1 with as many ciphers as there are figures to the right of the decimal point. For example, .075 has three figures to the right of the point; hence, $.075 \text{ ft.}=\frac{75}{1{,}000}=\frac{3}{40}$ ft.

Reducing a Common Fraction to a Decimal.—Divide the numerator by the denominator, and point off as many places as there have been ciphers annexed; thus, $\frac{3}{16}$ in. $=3.0000\div16=.1875$ in.

INVOLUTION

Involution is the process of multiplying a number by itself one or more times, the product obtained being called a certain *power* of the number.

If the number is multiplied by itself, the result is called the *square* of the number; thus, 9 is the square of 3, since $3\times3=9$.

If the square of a number is multiplied by the number, the result is called the *cube* of the number; thus, 27 is the cube of 3, since $3\times3\times3=27$.

The power to which a number is to be raised is indicated by a small figure, called an *exponent*, placed to the right and a little above the number; thus, 7^2 means that 7 is to be squared; 27^3 means that 27 is to be cubed, etc.

The operations of involution present no difficulty, as nothing but multiplication is involved, the number of times the number is to be taken as a factor being shown by the exponent. If the number is a fraction, raise both numerator and denominator to the power indicated.

A valuable little rule to memorize for finding the square of a mixed number in which the fraction is $\frac{1}{2}$, as $3\frac{1}{2}$, $10\frac{1}{2}$, etc., is as follows:

Rule.—*Multiply the next less whole number by the next greater, and add* $\frac{1}{4}$.

For example, the square of $6\frac{1}{2}$ is 6 (the next less number) $\times 7$ (the next greater) $+\frac{1}{4}=42\frac{1}{4}$; $(19\frac{1}{2})^2=19\times20+\frac{1}{4}=380\frac{1}{4}$; $(8\frac{1}{2})^2=8\times9+\frac{1}{4}=72\frac{1}{4}$, etc.

EVOLUTION

Evolution is the reverse of involution and is the process of finding one of the equal factors of a number, termed a *root*, which, multiplied by itself a certain number of times, will give a product equal to the given number. When the number is to be resolved into two equal factors, either one is called the *square root*; when there are to be three equal factors, each one is called the *cube root*; etc.

The operations to be performed are indicated by the radical sign $\sqrt{}$ and vinculum $\overline{\quad\quad}$, and by an index figure; for square root, the index figure is omitted. For example, $\sqrt{64}$ is read the square root of 64, which is 8, as $8 \times 8 = 64$; $\sqrt[3]{64}$ means cube root of 64, which is 4, as $4 \times 4 \times 4 = 64$.

A number is said to be a *perfect square*, or a *perfect cube*, etc. when the root consists only of a whole number; thus, 64 is a perfect cube, because the cube root is 4, without any decimal.

TABLE OF POWERS, ROOTS, AND RECIPROCALS

SIGNIFICANT FIGURES

By means of the following table the square, cube, square root, cube root, and reciprocal of any number may be obtained correct always to five significant figures, and in the majority of cases correct to six significant figures.

In any number, the figures beginning with the first digit* at the left and ending with the last digit at the right, are called the *significant figures* of the number. Thus, the number 405,800 has the four significant figures 4, 0, 5, 8; and the number .000090067 has the five significant figures 9, 0, 0, 6, and 7.

The part of a number consisting of its significant figures is called the *significant part* of the number. Thus, in the number 28,070, the significant part is 2807; in the number .00812, the significant part is 812; and in the number 170.3, the significant part is 1703.

In speaking of the significant figures or of the significant part of a number, the figures are considered, in their proper order, from the first digit at the left to the last digit at the right, but no attention is paid to the position of the decimal point. Hence, all numbers that differ only in the position of the decimal point have the same significant part. For example, .002103, 21.03, 21.030, and 210,300 have the same significant figures 2, 1, 0, and 3, and the same significant part 2103.

The *integral part* of a number is the part to the left of the decimal point.

It will be more convenient to explain first how to use the table for finding square and cube roots.

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*A cipher is not a digit.

SQUARE ROOT

To obtain the square root of a number, first point off the given number into periods of two figures each, beginning with the decimal point and proceeding to the left and right; for example, 12703, 1′27′03; 12.703, 12.70′30; 220000, 22′00′00; .000442, .00′04′42. Then, having pointed off the number, move the decimal point so that it will fall between the first and second periods of the significant part of the number. In the preceding numbers, the decimal point will be placed thus: 1.2703, 12.703, 22, 4.42.

If the number has three or less significant figures, find the significant part of the number in the column headed n; the square root will be found in the column headed $\sqrt{n}$ or $\sqrt{10n}$, according to whether the part to the left of the decimal point contains one figure or two figures. Thus, $\sqrt{4.42}=2.1024$, and $\sqrt{22}=\sqrt{10\times 2.20}=4.6904$. The decimal point is located in all cases by reference to the original number after pointing off into periods.

Rule.—*There will be as many figures in the root preceding the decimal point as there are periods preceding the decimal point in the given number; if the number is entirely decimal, the root is entirely decimal, and there will be as many ciphers following the decimal point in the root as there are cipher periods following the decimal point in the given number.*

Applying this rule, $\sqrt{220000}=469.04$ and $\sqrt{.000442}=.021024$.

The operation when the given number has more than three significant figures is best explained by an example.

EXAMPLE.—(*a*) $\sqrt{3.1416}=?$ (*b*) $\sqrt{2342.9}=?$

SOLUTION.—(*a*) As the first period contains but one figure, there is no need of moving the decimal point. In the column headed n^2, find two consecutive numbers, one a little greater and the other a little less than the given number; in the present case, $3.1684=1.78^2$ and $3.1329=1.77^2$. The first three figures of the root are therefore 177. Find the difference between the two numbers between which the given number falls, and the difference between the smaller number and the given number; divide the second difference by the first difference, carrying the quotient to three decimal places and increasing the second figure by 1 if the third is 5 or a greater digit.

The two figures of the quotient thus determined will be the fourth and fifth figures of the root. In the present example, dropping decimal points in the remainders, $3.1684-3.1329=355$, the first difference; $3.1416-3.1329=87$, the second difference; $87\div355=.245+$, or .25. Hence, $\sqrt{3.1416}=1.7725$.

(*b*) $\sqrt{2342.9}=?$ Pointing off into periods gives 23′42.90; moving the decimal point gives 23.4290; the first three figures of the root are 484; the first difference is $23.5225-23.4256=969$; the second difference is $23.4290-23.4256=34$; $34\div969=.035+$, or .04. Hence, $\sqrt{2342.9}=48.404$.

CUBE ROOT

The cube root of a number is found in a manner similar to that used for finding the square root. The difference being that the given number is pointed off into periods of three figures each; for example, 3141.6, 3′141.600; 67296428, 67′296′428; 601426.314, 601′426.314; .0000000217, .000′000′021′700. Then, having pointed off, move the decimal point so that it will fall between the first and second periods of the significant part of the number, as in square root. In the foregoing numbers the decimal point will be placed thus: 3.1416, 67.296428, 601.426314, and 21.7.

If the given number has three or less significant figures, find the significant part of the number in the column headed n; the cube root will be found in the column headed $\sqrt[3]{n}$, $\sqrt[3]{10\,n}$, or $\sqrt[3]{100\,n}$, according to whether one, two, or three figures precede the decimal point after it has been moved. Thus, the cube root of 21.7 will be found opposite 2.17, in column headed $\sqrt[3]{10\,n}$; the cube root of 2.17 will be found in the column headed $\sqrt[3]{n}$; and the cube root of 217, in the column headed $\sqrt[3]{100\,n}$, all on the same line. If the given number contains more than three significant figures, proceed exactly as described for square root except that the column headed n^3 is used.

EXAMPLE.—(*a*) $\sqrt[3]{.0000062417}=?$ (*b*) $\sqrt[3]{50932676}=?$

SOLUTION.—(*a*) Pointing off into periods, gives .000′006′241′700; moving the decimal point, gives 6.2417. The number falls between $6.22950=1.84^3$ and $6.33163=1.85^3$; the first difference $=10213$; the second difference is $6.24170-6.22950=1220$: $1220\div10213=.119+$, or .12, the fourth and fifth figures of the root. The decimal point is located by the rule previously given; hence, $\sqrt[3]{.0000062417}=.018412$.

(*b*) $\sqrt[3]{50932676}=?$ As the number contains more than six significant figures, reduce it to six significant figures by replacing all after the sixth figure with ciphers, increasing the sixth figure by 1 when the seventh is 5 or a greater digit. In other words, the first five figures of $\sqrt[3]{50932700}$ and of $\sqrt[3]{50932676}$ are the same. Pointing off into periods, gives 50'932'700; moving the decimal point, gives 50.9327, which falls between $50.6530=3.70^3$ and $51.0648=3.71^3$; the first difference is 4118; the second difference is 2797; $2797 \div 4118 = .679+$, or .68. The integral part of the root evidently contains three figures; hence, $\sqrt[3]{50932676}=370.68$, correct to five figures.

SQUARES AND CUBES

If the given number contains three or less significant figures, the square or cube is found in the column headed n^2 or n^3, opposite the given number in the column headed n. To find the square of a given number containing more than three significant figures, place the decimal point between the first and second significant figures and find in the column headed $\sqrt{n}$ or $\sqrt{10\,n}$ two consecutive numbers, one of which is a little greater and the other a little less than the given number. The remainder of the work is very similar to that described for extracting roots.

To locate the decimal point, employ the principle that the square of any number contains either twice as many figures as the number squared or twice as many less one. If the column headed $\sqrt{10\,n}$ is used, the square will contain twice as many figures, while if the column headed $\sqrt{n}$ is used, the square will contain twice as many figures as the number squared, less one. If the number contains an integral part, this principle is applied to the integral part only; if the number is wholly decimal, there will be twice as many ciphers following the decimal point in the square or twice as many plus one, as in the number squared, depending on whether $\sqrt{10\,n}$ or $\sqrt{n}$ column is used. For example, 273.42^2 will contain five figures in the integral part; 4516.2^2 will contain eight figures in the integral part, all after the fifth being denoted by ciphers;

$.0029453^2$ will have five ciphers following the decimal point; $.052436^2$ will have two ciphers following the decimal point.

EXAMPLE.—(*a*) $273.42^2 = ?$ (*b*) $.052436^2 = ?$

SOLUTION.—(*a*) Placing the decimal point between the first and second significant figures, the result is 2.7342; this number occurs between $2.73313 = \sqrt{7.47}$ and $2.73496 = \sqrt{7.48}$ in the column headed $\sqrt{n}$. The first difference is $2.73496 - 2.73313 = 183$; the second difference is $2.73420 - 2.73313 = 107$; and $107 \div 183 = .584+$, or .58. Hence, $273.42^2 = 74{,}758$, correct to five significant figures.

(*b*) Shifting the decimal point to between the first and second significant figures, gives the number 5.2436, which falls between $5.23450 = \sqrt{27.4}$ and $5.24404 = \sqrt{27.5}$. The first difference is 954; the second difference is 910; $910 \div 954 = .953+$, or .95. Hence, $.052436^2 = .0027495$, when carried to five significant figures.

A number is cubed in exactly the same manner, using the column headed $\sqrt[3]{n}$, $\sqrt[3]{10\,n}$, or $\sqrt[3]{100\,n}$, according to whether the first period of the significant part of the number contains one, two, or three figures, respectively. If the number contains an integral part, the number of figures in the integral part of the cube will be three times as many as in the given number if column headed $\sqrt[3]{100\,n}$ is used; it will be three times as many less 1 if the column headed $\sqrt[3]{10\,n}$ is used; and it will be three times as many less 2 if the column headed $\sqrt[3]{n}$ is used. If the given number is wholly decimal the cube will have three times, three times plus 1, or three times plus 2, as many ciphers following the decimal point as there are ciphers following the decimal point in the given number, depending on whether the $\sqrt[3]{100\,n}$, the $\sqrt[3]{10\,n}$, or the $\sqrt[3]{n}$ column is used.

EXAMPLE.—(*a*) $129.684^3 = ?$ (*b*) $.76442^3 = ?$ (*c*) $.032425^3 = ?$

SOLUTION.—(*a*) Placing the decimal point between the first and second significant figures, the number 1.29684 is found between $1.29664 = \sqrt[3]{2.18}$ and $1.29862 = \sqrt[3]{2.19}$. The first difference is 198; the second difference is 20; and $20 \div 198 = .101+$, or .10. Hence, the first five significant figures are 21810; the number of figures in the integral part of the cube is $3 \times 3 - 2 = 7$; and $129.684^3 = 2{,}181{,}000$, correct to five significant figures.

(*b*) 7.64420 occurs between $7.64032 = \sqrt[3]{446}$ and $7.64603 = \sqrt[3]{447}$. The first difference is 571; the second difference is 388; and $388 \div 571 = .679+$, or .68. Hence, the first five significant figures are 44668; the number of ciphers following the decimal point is $3 \times 0 = 0$; and $.76442^3 = .44668$, correct to five significant figures.

(*c*) 3.2425 falls between $3.24278 = \sqrt[3]{34.1}$ and $3.23961 = \sqrt[3]{34.0}$. The first difference is 317; the second difference is 289; $289 \div 317 = .911+$, or .91. Hence, the first five significant figures are 34091; the number of ciphers following the decimal point is $3 \times 1 + 1 = 4$; and $.032425^3 = .000034091$, correct to five significant figures.

RECIPROCALS

The *reciprocal* of a number is 1 divided by the number. By using reciprocals, division is changed into multiplication, as $a \div b = \frac{a}{b} = a \times \frac{1}{b}$. The table gives the reciprocals of all numbers, expressed with three significant figures, correct to six significant figures. By proceeding in a manner similar to that just described for powers and roots, the reciprocal of any number, correct to five significant figures, may be obtained.

The decimal point in the result may be located as follows: If the given number has an integral part, the number of ciphers following the decimal point in the reciprocal will be one less than the number of figures in the integral part of the given number; and if the given number is entirely decimal, the number of figures in the integral part of the reciprocal will be one greater than the number of ciphers following the decimal point in the given number. For example, the reciprocal of 3370 = .000296736 and of .00348 = 287.356.

When the number whose reciprocal is desired contains more than three significant figures, express the number to six significant figures (adding ciphers, if necessary, to make six figures) and find between what two numbers in the column headed $\frac{1}{n}$ the significant figures of the given number fall; then proceed in a manner similar to that previously described to determine the fourth and fifth figures.

Example.—(*a*) What is the reciprocal of 379.426?

(*b*) $\frac{1}{.0004692}=?$

Solution.—(*a*) .379426 falls between $.378788=\frac{1}{2.64}$ and $.380228=\frac{1}{2.63}$. The first difference is $380228-378788=1440$; the second difference is $380228-379426=802$; $802\div1440=.556+$, or .56. Hence, the first five significant figures are 26356, and the reciprocal of 379.426 is .0026356, to five significant figures.

(*b*) .469200 falls between $.469484=\frac{1}{2.13}$ and $.467290=\frac{1}{2.14}$. The first difference is 2194; the second difference is 284; $284\div2194=.129+$, or .13. Hence, $\frac{1}{.0004692}=2131.3$, correct to five significant figures.

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
1.01	1.0201	1.03030	1.00499	3.17805	1.00332	2.16159	4.65701	.990099
1.02	1.0404	1.06121	1.00995	3.19374	1.00662	2.16870	4.67233	.980392
1.03	1.0609	1.09273	1.01489	3.20936	1.00990	2.17577	4.68755	.970874
1.04	1.0816	1.12486	1.01980	3.22490	1.01316	2.18278	4.70267	.961539
1.05	1.1025	1.15763	1.02470	3.24037	1.01640	2.18976	4.71769	.952381
1.06	1.1236	1.19102	1.02956	3.25576	1.01961	2.19669	4.73262	.943396
1.07	1 1449	1.22504	1.03441	3.27109	1.02281	2.20358	4.74746	.934579
1.08	1.1664	1.25971	1.03923	3.28634	1.02599	2.21042	4.76220	.925926
1.09	1.1881	1.29503	1.04403	3.30151	1.02914	2.21722	4.77686	.917431
1.10	1.2100	1.33100	1.04881	3.31662	1.03228	2.22398	4.79142	.909091
1.11	1.2321	1 36763	1.05357	3.33167	1.03540	2.23070	4.80590	.900901
1.12	1.2544	1.40493	1.05830	3.34664	1.03850	2.23738	4.82028	.892857
1.13	1.2769	1.44290	1.06301	3.36155	1.04158	2.24402	4.83459	.884956
1.14	1.2996	1.48154	1.06771	3.37639	1.04464	2.25062	4.84881	.877193
1.15	1.3225	1.52088	1.07238	3.39116	1.04769	2.25718	4.86294	.869565
1.16	1.3456	1.56090	1.07703	3.40588	1.05072	2.26370	4.87700	.862069
1.17	1.3689	1.60161	1.08167	3.42053	1.05373	2.27019	4.89097	.854701
1.18	1.3924	1.64303	1.08628	3.43511	1.05672	2.27664	4.90487	.847458
1.19	1.4161	1.68516	1.09087	3.44964	1.05970	2.28305	4.91868	.840336
1.20	1.4400	1.72800	1.09545	3.46410	1.06266	2.28943	4.93242	.833333
1.21	1.4641	1.77156	1.10000	3.47851	1.06560	2.29577	4.94609	.826446
1.22	1.4884	1.81585	1.10454	3.49285	1.06853	2.30208	4.95968	.819672
1.23	1.5129	1.86087	1.10905	3.50714	1.07144	2.30835	4.97319	.813008
1.24	1.5376	1.90662	1.11355	3.52136	1.07434	2.31459	4.98663	.806452
1.25	1.5625	1.95313	1.11803	3.53553	1.07722	2.32080	5.00000	.800000
1.26	1.5876	2.00038	1.12250	3.54965	1.08008	2.32697	5.01330	.793651
1.27	1.6129	2.04838	1.12694	3.56371	1.08293	2.33310	5.02653	.787402
1.28	1.6384	2.09715	1.13137	3.57771	1.08577	2.33921	5.03968	.781250
1.29	1.6641	2.14669	1.13578	3.59166	1.08859	2.34529	5.05277	.775194
1.30	1.6900	2.19700	1.14018	3.60555	1.09139	2.35134	5.06580	.769231
1.31	1.7161	2.24809	1.14455	3.61939	1.09418	2.35735	5.07875	.763359
1.32	1.7424	2.29997	1.14891	3.63318	1.09696	2.36333	5.09164	.757576
1.33	1.7689	2.35264	1.15326	3.64692	1.09972	2.36928	5.10447	.751880
1.34	1.7956	2.40610	1.15758	3.66060	1.10247	2.37521	5.11723	.746269
1.35	1.8225	2.46038	1.16190	3.67423	1.10521	2.38110	5.12993	.740741
1.36	1.8496	2.51546	1.16619	3.68782	1.10793	2.38696	5.14256	.735294
1.37	1.8769	2.57135	1.17047	3.70135	1.11064	2.39280	5.15514	.729927
1.38	1.9044	2.62807	1.17473	3.71484	1.11334	2.39861	5.16765	.724638
1.39	1.9321	2.68562	1.17898	3.72827	1.11602	2.40439	5.18010	.719425
1.40	1.9600	2.74400	1.18322	3.74166	1.11869	2.41014	5.19249	.714286
1.41	1.9881	2.80322	1.18743	3.75500	1.12135	2.41587	5.20483	.709220
1.42	2.0164	2.86329	1.19164	3.76829	1.12399	2.42156	5.21710	.704225
1.43	2.0449	2.92421	1.19583	3.78153	1.12662	2.42724	5.22932	.699301
1.44	2.0736	2.98598	1.20000	3 79473	1.12924	2.43288	5.24148	.694444
1.45	2.1025	3.04863	1.20416	3.80789	1.13185	2.43850	5.25359	.689655
1.46	2.1316	3.11214	1.20830	3.82099	1.13445	2.44409	5.26564	.684932
1.47	2.1609	3.17652	1.21244	3.83406	1.13703	2.44966	5.27763	.680272
1.48	2.1904	3.24179	1.21655	3.84708	1.13960	2.45520	5.28957	.675676
1.49	2.2201	3.30795	1.22066	3.86005	1.14216	2.46072	5.30146	.671141
1.50	2.2500	3.37500	1.22474	3.87298	1.14471	2.46621	5.31329	.666667

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
1.51	2.2801	3.44295	1.22882	3.88587	1.14725	2.47168	5.32507	.662252
1.52	2.3104	3.51181	1.23288	3.89872	1.14978	2.47713	5.33680	.657895
1.53	2.3409	3.58158	1.23693	3.91152	1.15230	2.48255	5.34848	.653595
1.54	2.3716	3.65226	1.24097	3.92428	1.15480	2.48794	5.36011	.649351
1.55	2.4025	3.72388	1.24499	3.93700	1.15729	2.49332	5.37169	.645161
1.56	2.4336	3.79642	1.24900	3.94968	1.15978	2.49866	5.38321	.641026
1.57	2.4649	3.86989	1.25300	3.96232	1.16225	2.50399	5.39469	.636943
1.58	2.4964	3.94431	1.25698	3.97492	1.16471	2.50930	5.40612	.632911
1.59	2.5281	4.01968	1.26095	3.98748	1.16717	2.51458	5.41750	.628931
1.60	2.5600	4.09600	1.26491	4.00000	1.16961	2.51984	5.42884	.625000
1.61	2.5921	4.17328	1.26886	4.01248	1.17204	2.52508	5.44012	.621118
1.62	2.6244	4.25153	1.27279	4.02492	1.17446	2.53030	5.45136	.617284
1.63	2.6569	4.33075	1.27671	4.03733	1.17687	2.53549	5.46256	.613497
1.64	2.6896	4.41094	1.28062	4.04969	1.17927	2.54067	5.47370	.609756
1.65	2.7225	4.49213	1.28452	4.06202	1.18167	2.54582	5.48481	.606061
1.66	2.7556	4.57430	1.28841	4.07431	1.18405	2.55095	5.49586	.602410
1.67	2.7889	4.65746	1.29228	4.08656	1.18642	2.55607	5.50688	.598802
1.68	2.8224	4.74163	1.29615	4.09878	1.18878	2.56116	5.51785	.595238
1.69	2.8561	4.82681	1.30000	4.11096	1.19114	2.56623	5.52877	.591716
1.70	2.8900	4.91300	1.30384	4.12311	1.19348	2.57128	5.53966	.588235
1.71	2.9241	5.00021	1.30767	4.13521	1.19582	2.57631	5.55050	.584795
1.72	2.9584	5.08845	1.31149	4.14729	1.19815	2.58133	5.56130	.581395
1.73	2.9929	5.17772	1.31529	4.15933	1.20046	2.58632	5.57205	.578035
1.74	3.0276	5.26802	1.31909	4.17133	1.20277	2.59129	5.58277	.574713
1.75	3.0625	5.35938	1.32288	4.18330	1.20507	2.59625	5.59344	.571429
1.76	3.0976	5.45178	1.32665	4.19524	1.20736	2.60118	5.60408	.568182
1.77	3.1329	5.54523	1.33041	4.20714	1.20964	2.60610	5.61467	.564972
1.78	3.1684	5.63975	1.33417	4.21900	1.21192	2.61100	5.62523	.561798
1.79	3.2041	5.73534	1.33791	4.23084	1.21418	2.61588	5.63574	.558659
1.80	3.2400	5.83200	1.34164	4.24264	1.21644	2.62074	5.64622	.555556
1.81	3.2761	5.92974	1.34536	4.25441	1.21869	2.62558	5.65665	.552486
1.82	3.3124	6.02857	1.34907	4.26615	1.22093	2.63041	5.66705	.549451
1.83	3.3489	6.12849	1.35277	4.27785	1.22316	2.63522	5.67741	.546448
1.84	3.3856	6.22950	1.35647	4.28952	1.22539	2.64001	5.68773	.543478
1.85	3.4225	6.33163	1.36015	4.30116	1.22760	2.64479	5.69802	.540541
1.86	3.4596	6.43486	1.36382	4.31277	1.22981	2.64954	5.70827	.537634
1.87	3.4969	6.53920	1.36748	4.32435	1.23201	2.65428	5.71848	.534759
1.88	3.5344	6.64467	1.37113	4.33590	1.23420	2.65900	5.72865	.531915
1.89	3.5721	6.75127	1.37477	4.34741	1.23639	2.66371	5.73879	.529101
1.90	3.6100	6.85900	1.37840	4.35890	1.23856	2.66840	5.74890	.526316
1.91	3.6481	6.96787	1.38203	4.37035	1.24073	2.67307	5.75897	.523560
1.92	3.6864	7.07789	1.38564	4.38178	1.24289	2.67773	5.76900	.520833
1.93	3.7249	7.18906	1.38924	4.39318	1.24505	2.68237	5.77900	.518135
1.94	3.7636	7.30138	1.39284	4.40454	1.24719	2.68700	5.78896	.515464
1.95	3.8025	7.41488	1.39642	4.41588	1.24933	2.69161	5.79889	.512821
1.96	3.8416	7.52954	1.40000	4.42719	1.25146	2.69620	5.80879	.510204
1.97	3.8809	7.64537	1.40357	4.43847	1.25359	2.70078	5.81865	.507614
1.98	3.9204	7.76239	1.40712	4.44972	1.25571	2.70534	5.82848	.505051
1.99	3.9601	7.88060	1.41067	4.46094	1.25782	2.70989	5.83827	.502513
2.00	4.0000	8.00000	1.41421	4.47214	1.25992	2.71442	5.84804	.500000

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
2.01	4.0401	8.12060	1.41774	4.48330	1.26202	2.71893	5.85777	.497512
2.02	4.0804	8.24241	1.42127	4.49444	1.26411	2.72343	5.86746	.495050
2.03	4.1209	8.36543	1.42478	4.50555	1.26619	2.72792	5.87713	.492611
2.04	4.1616	8.48966	1.42829	4.51664	1.26827	2.73239	5.88677	.490196
2.05	4.2025	8.61513	1.43178	4.52769	1.27033	2.73685	5.89637	.487805
2.06	4.2436	8.74182	1.43527	4.53872	1.27240	2.74129	5.90594	.485437
2.07	4.2849	8.86974	1.43875	4.54973	1.27445	2.74572	5.91548	.483092
2.08	4.3264	8.99891	1.44222	4.56070	1.27650	2.75014	5.92499	.480769
2.09	4.3681	9.12933	1.44568	4.57165	1.27854	2.75454	5.93447	.478469
2.10	4.4100	9.26100	1.44914	4.58258	1.28058	2.75893	5.94392	.476191
2.11	4.4521	9.39393	1.45258	4.59347	1.28261	2.76330	5.95334	.473934
2.12	4.4944	9.52813	1.45602	4.60435	1.28463	2.76766	5.96273	.471698
2.13	4.5369	9.66360	1.45945	4.61519	1.28665	2.77200	5.97209	.469484
2.14	4.5796	9.80034	1.46287	4.62601	1.28866	2.77633	5.98142	.467290
2.15	4.6225	9.93838	1.46629	4.63681	1.29066	2.78065	5.99073	.465116
2.16	4.6656	10.0777	1.46969	4.64758	1.29266	2.78495	6.00000	.462963
2.17	4.7089	10.2183	1.47309	4.65833	1.29465	2.78924	6.00925	.460830
2.18	4.7524	10.3602	1.47648	4.66905	1.29664	2.79352	6.01846	.458716
2.19	4.7961	10.5035	1.47986	4.67974	1.29862	2.79779	6.02765	.456621
2.20	4.8400	10.6480	1.48324	4.69042	1.30059	2.80204	6.03681	.454546
2.21	4.8841	10.7939	1.48661	4.70106	1.30256	2.80628	6.04594	.452489
2.22	4.9284	10.9410	1.48997	4.71169	1.30452	2.81051	6.05505	.450451
2.23	4.9729	11.0896	1.49332	4.72229	1.30648	2.81472	6.06413	.448431
2.24	5.0176	11.2394	1.49666	4.73286	1.30843	2.81892	6.07318	.446429
2.25	5.0625	11.3906	1.50000	4.74342	1.31037	2.82311	6.08220	.444444
2.26	5.1076	11.5432	1.50333	4.75395	1.31231	2.82728	6.09120	.442478
2.27	5.1529	11.6971	1.50665	4.76445	1.31424	2.83145	6.10017	.440529
2.28	5.1984	11.8524	1.50997	4.77493	1.31617	2.83560	6.10911	.438597
2.29	5.2441	12.0090	1.51327	4.78539	1.31809	2.83974	6.11803	.436681
2.30	5.2900	12.1670	1.51658	4.79583	1.32001	2.84387	6.12693	.434783
2.31	5.3361	12.3264	1.51987	4.80625	1.32192	2.84798	6.13579	.432900
2.32	5.3824	12.4872	1.52315	4.81664	1.32382	2.85209	6.14463	.431035
2.33	5.4289	12.6493	1.52643	4.82701	1.32572	2.85618	6.15345	.429185
2.34	5.4756	12.8129	1.52971	4.83735	1.32761	2.86026	6.16224	.427350
2.35	5.5225	12.9779	1.53297	4.84768	1.32950	2.86433	6.17101	.425532
2.36	5.5696	13.1443	1.53623	4.85798	1.33139	2.86838	6.17975	.423729
2.37	5.6169	13.3121	1.53948	4.86826	1.33326	2.87243	6.18846	.421941
2.38	5.6644	13.4813	1.54272	4.87852	1.33514	2.87646	6.19715	.420168
2.39	5.7121	13.6519	1.54596	4.88876	1.33700	2.88049	6.20582	.418410
2.40	5.7600	13.8240	1.54919	4.89898	1.33887	2.88450	6.21447	.416667
2.41	5.8081	13.9975	1.55242	4.90918	1.34072	2.88850	6.22308	.414938
2.42	5.8564	14.1725	1.55563	4.91935	1.34257	2.89249	6.23168	.413223
2.43	5.9049	14.3489	1.55885	4.92950	1.34442	2.89647	6.24025	.411523
2.44	5.9536	14.5268	1.56205	4.93964	1.34626	2.90044	6.24880	.409836
2.45	6.0025	14.7061	1.56525	4.94975	1.34810	2.90439	6.25732	.408163
2.46	6.0516	14.8869	1.56844	4.95984	1.34993	2.90834	6.26583	.406504
2.47	6.1009	15.0692	1.57162	4.96991	1.35176	2.91227	6.27431	.404858
2.48	6.1504	15.2530	1.57480	4.97996	1.35358	2.91620	6.28276	.403226
2.49	6.2001	15.4382	1.57797	4.98999	1.35540	2.92011	6.29119	.401606
2.50	6.2500	15.6250	1.58114	5.00000	1.35721	2.92402	6.29961	.400000

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
2.51	6.3001	15.8133	1.58430	5.00999	1.35902	2.92791	6.30799	.398406
2.52	6.3504	16.0030	1.58745	5.01996	1.36082	2.93179	6.31636	.396825
2.53	6.4009	16.1943	1.59060	5.02991	1.36262	2.93567	6.32470	.395257
2.54	6.4516	16.3871	1.59374	5.03984	1.36441	2.93953	6.33303	.393701
2.55	6.5025	16.5814	1.59687	5.04975	1.36620	2.94338	6.34133	.392157
2.56	6.5536	16.7772	1.60000	5.05964	1.36798	2.94723	6.34960	.390625
2.57	6.6049	16.9746	1.60312	5.06952	1.36976	2.95106	6.35786	.389105
2.58	6.6564	17.1735	1.60624	5.07937	1.37153	2.95488	6.36610	.387597
2.59	6.7081	17.3740	1.60935	5.08920	1.37330	2.95869	6.37431	.386100
2.60	6.7600	17.5760	1.61245	5.09902	1.37507	2.96250	6.38250	.384615
2.61	6.8121	17.7796	1.61555	5.10882	1.37683	2.96629	6.39068	.383142
2.62	6.8644	17.9847	1.61864	5.11859	1.37859	2.97007	6.39883	.381679
2.63	6.9169	18.1914	1.62173	5.12835	1.38034	2.97385	6.40696	.380228
2.64	6.9696	18.3997	1.62481	5.13809	1.38208	2.97761	6.41507	.378788
2.65	7.0225	18.6096	1.62788	5.14782	1.38383	2.98137	6.42316	.377359
2.66	7.0756	18.8211	1.63095	5.15752	1.38557	2.98511	6.43123	.375940
2.67	7.1289	19.0342	1.63401	5.16720	1.38730	2.98885	6.43928	.374532
2.68	7.1824	19.2488	1.63707	5.17687	1.38903	2.99257	6.44731	.373134
2.69	7.2361	19.4651	1.64012	5.18652	1.39076	2.99629	6.45531	.371747
2.70	7.2900	19.6830	1.64317	5.19615	1.39248	3.00000	6.46330	.370370
2.71	7.3441	19.9025	1.64621	5.20577	1.39419	3.00370	6.47127	.369004
2.72	7.3984	20.1236	1.64924	5.21536	1.39591	3.00739	6.47922	.367647
2.73	7.4529	20.3464	1.65227	5.22494	1.39761	3.01107	6.48715	.366300
2.74	7.5076	20.5708	1.65529	5.23450	1.39932	3.01474	6.49507	.364964
2.75	7.5625	20.7969	1.65831	5.24404	1.40102	3.01841	6.50296	.363636
2.76	7.6176	21.0246	1.66132	5.25357	1.40272	3.02206	6.51083	.362319
2.77	7.6729	21.2539	1.66433	5.26308	1.40441	3.02571	6.51868	.361011
2.78	7.7284	21.4850	1.66733	5.27257	1.40610	3.02934	6.52652	.359712
2.79	7.7841	21.7176	1.67033	5.28205	1.40778	3.03297	6.53434	.358423
2.80	7.8400	21.9520	1.67332	5.29150	1.40946	3.03659	6.54213	.357142
2.81	7.8961	22.1880	1.67631	5.30094	1.41114	3.04020	6.54991	.355872
2.82	7.9524	22.4258	1.67929	5.31037	1.41281	3.04380	6.55767	.354610
2.83	8.0089	22.6652	1.68226	5.31977	1.41448	3.04740	6.56541	.353357
2.84	8.0656	22.9063	1.68523	5.32917	1.41614	3.05098	6.57314	.352113
2.85	8.1225	23.1491	1.68819	5.33854	1.41780	3.05456	6.58084	.350877
2.86	8.1796	23.3937	1.69115	5.34790	1.41946	3.05813	6.58853	.349650
2.87	8.2369	23.6399	1.69411	5.35724	1.42111	3.06169	6.59620	.348432
2.88	8.2944	23.8879	1.69706	5.36656	1.42276	3.06524	6.60385	.347222
2.89	8.3521	24.1376	1.70000	5.37587	1.42440	3.06878	6.61149	.346021
2.90	8.4100	24.3890	1.70294	5.38516	1.42604	3.07232	6.61911	.344828
2.91	8.4681	24.6422	1.70587	5.39444	1.42768	3.07585	6.62671	.343643
2.92	8.5264	24.8971	1.70880	5.40370	1.42931	3.07936	6.63429	.342466
2.93	8.5849	25.1538	1.71172	5.41295	1.43094	3.08287	6.64185	.341297
2.94	8.6436	25.4122	1.71464	5.42218	1.43257	3.08638	6.64940	.340136
2.95	8.7025	25.6724	1.71756	5.43139	1.43419	3.08987	6.65693	.338983
2.96	8.7616	25.9343	1.72047	5.44059	1.43581	3.09336	6.66444	.337838
2.97	8.8209	26.1981	1.72337	5.44977	1.43743	3.09684	6.67194	.336700
2.98	8.8804	26.4636	1.72627	5.45894	1.43904	3.10031	6.67942	.335571
2.99	8.9401	26.7309	1.72916	5.46809	1.44065	3.10378	6.68688	.334448
3.00	9.0000	27.0000	1.73205	5.47723	1.44225	3.10723	6.69433	.333333

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
3.01	9.0601	27.2709	1.73494	5.48635	1.44385	3.11068	6.70176	.332226
3.02	9.1204	27.5436	1.73781	5.49545	1.44545	3.11412	6.70917	.331126
3.03	9.1809	27.8181	1.74069	5.50454	1.44704	3.11755	6.71657	.330033
3.04	9.2416	28.0945	1.74356	5.51362	1.44863	3.12098	6.72395	.328947
3.05	9.3025	28.3726	1.74642	5.52268	1 45022	3.12440	6.73132	.327869
3.06	9.3636	28.6526	1.74929	5.53173	1.45180	3.12781	6.73866	.326797
3.07	9.4249	28.9344	1.75214	5.54076	1.45338	3.13121	6.74600	.325733
3.08	9.4864	29.2181	1.75499	5.54977	1.45496	3.13461	6.75331	.324675
3.09	9.5481	29.5036	1.75784	5.55878	1.45653	3.13800	6.76061	.323625
3.10	9.6100	29.7910	1.76068	5.56776	1.45810	3.14138	6.76790	.322581
3.11	9.6721	30.0802	1.76352	5.57674	1.45967	3.14475	6.77517	.321543
3.12	9.7344	30.3713	1.76635	5.58570	1.46123	3.14812	6.78242	.320513
3.13	9.7969	30.6643	1.76918	5.59464	1.46279	3.15148	6.78966	.319489
3.14	9.8596	30.9591	1.77200	5.60357	1.46434	3.15484	6.79688	.318471
3.15	9.9225	31.2559	1.77482	5.61249	1.46590	3.15818	6.80409	.317460
3.16	9.9856	31.5545	1.77764	5.62139	1.46745	3.16152	6.81128	.316456
3.17	10.0489	31.8550	1.78045	5.63028	1.46899	3.16485	6.81846	.315457
3.18	10.1124	32.1574	1.78326	5.63915	1.47054	3.16817	6.82562	.314465
3.19	10.1761	32.4618	1.78606	5.64801	1.47208	3.17149	6.83277	.313480
3.20	10.2400	32.7680	1.78885	5.65685	1.47361	3.17480	6.83990	.312500
3.21	10.3041	33.0762	1.79165	5.66569	1.47515	3.17811	6.84702	.311527
3.22	10.3684	33.3862	1.79444	5.67450	1.47668	3.18140	6.85412	.310559
3.23	10.4329	33.6983	1.79722	5.68331	1.47820	3.18469	6.86121	.309598
3.24	10.4976	34.0122	1.80000	5.69210	1.47973	3.18798	6.86829	.308642
3.25	10.5625	34.3281	1.80278	5.70088	1.48125	3.19125	6.87534	.307692
3.26	10.6276	34.6460	1.80555	5.70964	1.48277	3.19452	6.88239	.306749
3.27	10.6929	34.9658	1.80831	5.71839	1.48428	3.19779	6.88942	.305810
3.28	10.7584	35.2876	1.81108	5.72713	1.48579	3.20104	6.89643	.304878
3.29	10.8241	35.6129	1.81384	5.73585	1.48730	3.20429	6.90344	.303951
3.30	10.8900	35.9370	1.81659	5.74456	1.48881	3.20753	6.91042	.303030
3.31	10.9561	36.2647	1.81934	5.75326	1.49031	3.21077	6.91740	.302115
3.32	11.0224	36.5944	1.82209	5.76194	1.49181	3.21400	6.92436	.301205
3.33	11.0889	36.9260	1.82483	5.77062	1.49330	3.21723	6.93130	.300300
3.34	11.1556	37.2597	1.82757	5.77927	1.49480	3.22044	6.93823	.299401
3.35	11.2225	37.5954	1.83030	5.78792	1.49629	3.22365	6.94515	.298508
3.36	11.2896	37.9331	1.83303	5.79655	1.49777	3.22686	6.95205	.297619
3.37	11.3569	38.2728	1.83576	5.80517	1.49926	3.23005	6.95894	.296736
3.38	11.4244	38.6145	1.83848	5.81378	1.50074	3.23325	6.96582	.295858
3.39	11.4921	38.9582	1.84120	5.82237	1.50222	3.23643	6.97268	.294985
3.40	11.5600	39.3040	1.84391	5.83095	1.50369	3.23961	6.97953	.294118
3.41	11.6281	39.6518	1.84662	5.83952	1.50517	3.24278	6.98637	.293255
3.42	11.6964	40.0017	1.84932	5.84808	1.50664	3.24595	6.99319	.292398
3.43	11.7649	40.3536	1.85203	5.85662	1.50810	3.24911	7.00000	.291545
3.44	11.8336	40.7076	1.85472	5.86515	1.50957	3.25227	7.00680	.290698
3.45	11.9025	41.0636	1.85742	5.87367	1.51103	3.25542	7.01358	.289855
3.46	11.9716	41.4217	1.86011	5.88218	1.51249	3.25856	7.02035	.289017
3.47	12.0409	41.7819	1.86279	5.89067	1.51394	3.26169	7.02711	.288184
3.48	12.1104	42.1442	1.86548	5.89915	1.51540	3.26482	7.03385	.287356
3.49	12.1801	42.5085	1.86815	5.90762	1.51685	3.26795	7.04058	.286533
3.50	12.2500	42.8750	1.87083	5.91608	1.51829	3.27107	7.04730	.285714

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
3.51	12.3201	43.2436	1.87350	5.92453	1.51974	3.27418	7.05400	.284900
3.52	12.3904	43.6142	1.87617	5.93296	1.52118	3.27729	7.06070	.284091
3.53	12.4609	43.9870	1.87883	5.94138	1.52262	3.28039	7.06738	.283286
3.54	12.5316	44.3619	1.88149	5.94979	1.52406	3.28348	7.07404	.282486
3.55	12.6025	44.7389	1.88414	5.95819	1.52549	3.28657	7.08070	.281690
3.56	12.6736	45.1180	1.88680	5.96657	1.52692	3.28965	7.08734	.280899
3.57	12.7449	45.4993	1.88944	5.97495	1.52835	3.29273	7.09397	.280112
3.58	12.8164	45.8827	1.89209	5.98331	1.52978	3.29580	7.10059	.279330
3.59	12.8881	46.2683	1.89473	5.99166	1.53120	3.29887	7.10719	.278552
3.60	12.9600	46.6560	1.89737	6.00000	1.53262	3.30193	7.11379	.277778
3.61	13.0321	47.0459	1.90000	6.00833	1.53404	3.30498	7.12037	.277008
3.62	13.1044	47.4379	1.90263	6.01664	1.53545	3.30803	7.12694	.276243
3.63	13.1769	47.8321	1.90526	6.02495	1.53686	3.31107	7.13349	.275482
3.64	13.2496	48.2285	1.90788	6.03324	1.53827	3.31411	7.14004	.274725
3.65	13.3225	48.6271	1.91050	6.04152	1.53968	3.31714	7.14657	.273973
3.66	13.3956	49.0279	1.91311	6.04979	1.54109	3.32017	7.15309	.273224
3.67	13.4689	49.4309	1.91572	6.05805	1.54249	3.32319	7.15960	.272480
3.68	13.5424	49.8360	1.91833	6.06630	1.54389	3.32621	7.16610	.271739
3.69	13.6161	50.2434	1.92094	6.07454	1.54529	3.32922	7.17258	.271003
3.70	13.6900	50.6530	1.92354	6.08276	1.54668	3.33222	7.17905	.270270
3.71	13.7641	51.0648	1.92614	6.09098	1.54807	3.33522	7.18552	.269542
3.72	13.8384	51.4788	1.92873	6.09918	1.54946	3.33822	7.19197	.268817
3.73	13.9129	51.8951	1.93132	6.10737	1.55085	3.34120	7.19841	.268097
3.74	13.9876	52.3136	1.93391	6.11555	1.55223	3.34419	7.20483	.267380
3.75	14.0625	52.7344	1.93649	6.12372	1.55362	3.34716	7.21125	.266667
3.76	14.1376	53.1574	1.93907	6.13188	1.55500	3.35014	7.21765	.265957
3.77	14.2129	53.5826	1.94165	6.14003	1.55637	3.35310	7.22405	.265252
3.78	14.2884	54.0102	1.94422	6.14817	1.55775	3.35607	7.23043	.264550
3.79	14.3641	54.4399	1.94679	6.15630	1.55912	3.35902	7.23680	.263852
3.80	14.4400	54.8720	1.94936	6.16441	1.56049	3.36198	7.24316	.263158
3.81	14.5161	55.3063	1.95192	6.17252	1.56186	3.36492	7.24950	.262467
3.82	14.5924	55.7430	1.95448	6.18061	1.56322	3.36786	7.25584	.261780
3.83	14.6689	56.1819	1.95704	6.18870	1.56459	3.37080	7.26217	.261097
3.84	14.7456	56.6231	1.95959	6.19677	1.56595	3.37373	7.26848	.260417
3.85	14.8225	57.0666	1.96214	6.20484	1.56731	3.37666	7.27479	.259740
3.86	14.8996	57.5125	1.96469	6.21289	1.56866	3.37958	7.28108	.259067
3.87	14.9769	57.9606	1.96723	6.22093	1.57001	3.38249	7.28736	.258398
3.88	15.0544	58.4111	1.96977	6.22896	1.57137	3.38540	7.29363	.257732
3.89	15.1321	58.8639	1.97231	6.23699	1.57271	3.38831	7.29989	.257069
3.90	15.2100	59.3190	1.97484	6.24500	1.57406	3.39121	7.30614	.256410
3.91	15.2881	59.7765	1.97737	6.25300	1.57541	3.39411	7.31238	.255755
3.92	15.3664	60.2363	1.97990	6.26099	1.57675	3.39700	7.31861	.255102
3.93	15.4449	60.6985	1.98242	6.26897	1.57809	3.39988	7.32483	.254453
3.94	15.5236	61.1630	1.98494	6.27694	1.57942	3.40277	7.33104	.253807
3.95	15.6025	61.6299	1.98746	6.28490	1.58076	3.40564	7.33723	.253165
3.96	15.6816	62.0991	1.98997	6.29285	1.58209	3.40851	7.34342	.252525
3.97	15.7609	62.5708	1.99249	6.30079	1.58342	3.41138	7.34960	.251889
3.98	15.8404	63.0448	1.99499	6.30872	1.58475	3.41424	7.35576	.251256
3.99	15.9201	63.5212	1.99750	6.31664	1.58608	3.41710	7.36192	.250627
4.00	16.0000	64.0000	2.00000	6.32456	1.58740	3.41995	7.36806	.250000

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
4.01	16.0801	64.4812	2.00250	6.33246	1.58872	3.42280	7.37420	.249377
4.02	16.1604	64.9648	2.00499	6.34035	1.59004	3.42564	7.38032	.248756
4.03	16.2409	65.4508	2.00749	6.34823	1.59136	3.42848	7.38644	.248139
4.04	16.3216	65.9393	2.00998	6.35610	1.59267	3.43131	7.39254	.247525
4.05	16.4025	66.4301	2.01246	6.36396	1.59399	3.43414	7.39864	.246914
4.06	16.4836	66.9234	2.01494	6.37181	1.59530	3.43697	7.40472	.246305
4.07	16.5649	67.4191	2.01742	6.37966	1.59661	3.43979	7.41080	.245700
4.08	16.6464	67.9173	2.01990	6.38749	1.59791	3.44260	7.41686	.245098
4.09	16.7281	68.4179	2.02237	6.39531	1.59922	3.44541	7.42291	.244499
4.10	16.8100	68.9210	2.02485	6.40312	1.60052	3.44822	7.42896	.243902
4.11	16.8921	69.4265	2.02731	6.41093	1.60182	3.45102	7.43499	.243309
4.12	16.9744	69.9345	2.02978	6.41872	1.60312	3.45382	7.44102	.242718
4.13	17.0569	70.4450	2.03224	6.42651	1.60441	3.45661	7.44703	.242131
4.14	17.1396	70.9579	2.03470	6.43428	1.60571	3.45939	7.45304	.241546
4.15	17.2225	71.4734	2.03715	6.44205	1.60700	3.46218	7.45904	.240964
4.16	17.3056	71.9913	2.03961	6.44981	1.60829	3.46496	7.46502	.240385
4.17	17.3889	72.5117	2.04206	6.45755	1.60958	3.46773	7.47100	.239808
4.18	17.4724	73.0346	2.04450	6.46529	1.61086	3.47050	7.47697	.239234
4.19	17.5561	73.5601	2.04695	6.47302	1.61215	3.47327	7.48292	.238664
4.20	17.6400	74.0880	2.04939	6.48074	1.61343	3.47603	7.48887	.238095
4.21	17.7241	74.6185	2.05183	6.48845	1.61471	3.47878	7.49481	.237530
4.22	17.8084	75.1514	2.05426	6.49615	1.61599	3.48154	7.50074	.236967
4.23	17.8929	75.6870	2.05670	6.50385	1.61726	3.48428	7.50666	.236407
4.24	17.9776	76.2250	2.05913	6.51153	1.61853	3.48703	7.51257	.235849
4.25	18.0625	76.7656	2.06155	6.51920	1.61981	3.48977	7.51847	.235294
4.26	18.1476	77.3088	2.06398	6.52687	1.62108	3.49250	7.52437	.234742
4.27	18.2329	77.8545	2.06640	6.53452	1.62234	3.49523	7.53025	.234192
4.28	18.3184	78.4028	2.06882	6.54217	1.62361	3.49796	7.53612	.233645
4.29	18.4041	78.9536	2.07123	6.54981	1.62487	3.50068	7.54199	.233100
4.30	18.4900	79.5070	2.07364	6.55744	1.62613	3.50340	7.54784	.232558
4.31	18.5761	80.0630	2.07605	6.56506	1.62739	3.50611	7.55369	.232019
4.32	18.6624	80.6216	2.07846	6.57267	1.62865	3.50882	7.55953	.231482
4.33	18.7489	81.1827	2.08087	6.58027	1.62991	3.51153	7.56535	.230947
4.34	18.8356	81.7465	2.08327	6.58787	1.63116	3.51423	7.57117	.230415
4.35	18.9225	82.3129	2.08567	6.59545	1.63241	3.51692	7.57698	.229885
4.36	19.0096	82.8819	2.08806	6.60303	1.63366	3.51962	7.58279	.229358
4.37	19.0969	83.4535	2.09045	6.61060	1.63491	3.52231	7.58858	.228833
4.38	19.1844	84.0277	2.09284	6.61816	1.63616	3.52499	7.59436	.228311
4.39	19.2721	84.6045	2.09523	6.62571	1.63740	3.52767	7.60014	.227790
4.40	19.3600	85.1840	2.09762	6.63325	1.63864	3.53035	7.60590	.227273
4.41	19.4481	85.7661	2.10000	6.64078	1.63988	3.53302	7.61166	.226757
4.42	19.5364	86.3509	2.10238	6.64831	1.64112	3.53569	7.61741	.226244
4.43	19.6249	86.9383	2.10476	6.65582	1.64236	3.53835	7.62315	.225734
4.44	19.7136	87.5284	2.10713	6.66333	1.64359	3.54101	7.62888	.225225
4.45	19.8025	88.1211	2.10950	6.67083	1.64483	3.54367	7.63461	.224719
4.46	19.8916	88.7165	2.11187	6.67832	1.64606	3.54632	7.64032	.224215
4.47	19.9809	89.3146	2.11424	6.68581	1.64729	3.54897	7.64603	.223714
4.48	20.0704	89.9154	2.11660	6.69328	1.64851	3.55162	7.65172	.223214
4.49	20.1601	90.5188	2.11896	6.70075	1.64974	3.55426	7.65741	.222717
4.50	20.2500	91.1250	2.12132	6.70820	1.65096	3.55689	7.66309	.222222

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
4.51	20.3401	91.7339	2.12368	6.71565	1.65219	3.55953	7.66877	.221730
4.52	20.4304	92.3454	2.12603	6.72309	1.65341	3.56215	7.67443	.221239
4.53	20.5209	92.9597	2.12838	6.73053	1.65462	3.56478	7.68009	.220751
4.54	20.6116	93.5767	2.13073	6.73795	1.65584	3.56740	7.68573	.220264
4.55	20.7025	94.1964	2.13307	6.74537	1.65706	3.57002	7.69137	.219780
4.56	20.7936	94.8188	2.13542	6.75278	1.65827	3.57263	7.69700	.219298
4.57	20.8849	95.4440	2.13776	6.76018	1.65948	3.57524	7.70262	.218818
4.58	20.9764	96.0719	2.14009	6.76757	1.66069	3.57785	7.70824	.218341
4.59	21.0681	96.7026	2.14243	6.77495	1.66190	3.58045	7.71384	.217865
4.60	21.1600	97.3360	2.14476	6.78233	1.66310	3.58305	7.71944	.217391
4.61	21.2521	97.9722	2 14709	6.78970	1.66431	3.58564	7.72503	.216920
4.62	21.3444	98.6111	2.14942	6.79706	1.66551	3.58823	7.73061	.216450
4.63	21.4369	99.2528	2.15174	6.80441	1.66671	3.59082	7.73619	.215983
4.64	21.5296	99.8973	2.15407	6.81175	1.66791	3.59340	7.74175	.215517
4.65	21.6225	100.545	2.15639	6.81909	1.66911	3.59598	7.74731	.215054
4.66	21.7156	101.195	2.15870	6.82642	1.67030	3.59856	7.75286	.214592
4.67	21.8089	101.848	2.16102	6.83374	1.67150	3.60113	7.75840	.214133
4.68	21.9024	102.503	2.16333	6.84105	1.67269	3.60370	7.76394	.213675
4.69	21.9961	103.162	2.16564	6.84836	1.67388	3.60626	7.76946	.213220
4.70	22.0900	103.823	2.16795	6.85565	1.67507	3.60883	7.77498	.212766
4.71	22.1841	104.487	2.17025	6.86294	1.67626	3.61138	7.78049	.212314
4.72	22.2784	105.154	2.17256	6.87023	1.67744	3.61394	7.78599	.211864
4.73	22.3729	105.824	2.17486	6.87750	1.67863	3.61649	7.79149	.211417
4.74	22.4676	106.496	2.17715	6.88477	1.67981	3.61904	7.79697	.210971
4.75	22.5625	107.172	2.17945	6.89202	1.68099	3.62158	7.80245	.210526
4.76	22.6576	107.850	2.18174	6.89928	1.68217	3.62412	7.80793	.210084
4.77	22.7529	108.531	2.18403	6.90652	1.68334	3.62665	7.81339	.209644
4.78	22.8484	109.215	2.18632	6.91375	1.68452	3.62919	7.81885	.209205
4.79	22.9441	109.902	2.18861	6.92098	1.68569	3.63171	7.82429	.208768
4.80	23.0400	110.592	2.19089	6.92820	1.68687	3.63424	7.82974	.208333
4.81	23.1361	111.285	2.19317	6.93542	1.68804	3.63676	7.83517	.207900
4.82	23.2324	111.980	2.19545	6.94262	1.68920	3.63928	7.84059	.207469
4.83	23.3289	112.679	2.19773	6.94982	1.69037	3.64180	7.84601	.207039
4.84	23.4256	113.380	2.20000	6.95701	1.69154	3.64431	7.85142	.206612
4.85	23.5225	114.084	2.20227	6.96419	1.69270	3.64682	7.85683	.206186
4.86	23.6196	114.791	2.20454	6.97137	1.69386	3.64932	7.86222	.205761
4.87	23.7169	115.501	2.20681	6.97854	1.69503	3.65182	7.86761	.205339
4.88	23.8144	116.214	2.20907	6.98570	1.69619	3.65432	7.87299	.204918
4.89	23.9121	116.930	2.21133	6.99285	1.69734	3.65682	7.87837	.204499
4.90	24.0100	117.649	2.21359	7.00000	1.69850	3.65931	7.88374	.204082
4.91	24.1081	118.371	2.21585	7.00714	1.69965	3.66179	7.88909	.203666
4.92	24.2064	119.095	2.21811	7.01427	1.70081	3 66428	7.89445	.203252
4.93	24.3049	119.823	2.22036	7.02140	1.70196	3.66676	7.89979	.202840
4.94	24.4036	120.554	2 22261	7.02851	1.70311	3.66924	7.90513	.202429
4.95	24.5025	121.287	2.22486	7.03562	1.70426	3.67171	7.91046	.202020
4.96	24.6016	122.024	2.22711	7.04273	1.70540	3.67418	7.91578	.201613
4.97	24.7009	122.763	2.22935	7.04982	1.70655	3.67665	7.92110	.201207
4.98	24.8004	123.506	2.23159	7.05691	1.70769	3.67911	7.92641	.200803
4.99	24.9001	124.251	2.23383	7.06399	1.70884	3.68157	7.93171	.200401
5.00	25.0000	125.000	2.23607	7.07107	1.70998	3.68403	7.93701	.200000

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
5.01	25.1001	125.752	2.23830	7.07814	1.71112	3.68649	7.94229	.199601
5.02	25.2004	126.506	2.24054	7.08520	1.71225	3.68894	7.94757	.199203
5.03	25.3009	127.264	2.24277	7.09225	1.71339	3.69138	7.95285	.198807
5.04	25.4016	128.024	2.24499	7.09930	1.71452	3.69383	7.95811	.198413
5.05	25.5025	128.788	2.24722	7.10634	1.71566	3.69627	7.96337	.198020
5.06	25.6036	129.554	2.24944	7.11337	1.71679	3.69871	7.96863	.197629
5.07	25.7049	130.324	2.25167	7.12039	1.71792	3.70114	7.97387	.197239
5.08	25.8064	131.097	2.25389	7.12741	1.71905	3.70358	7.97911	.196850
5.09	25.9081	131.872	2.25610	7.13442	1.72017	3.70600	7.98434	.196464
5.10	26.0100	132.651	2.25832	7.14143	1.72130	3.70843	7.98957	.196078
5.11	26.1121	133.433	2.26053	7.14843	1.72242	3.71085	7.99479	.195695
5.12	26.2144	134.218	2.26274	7.15542	1.72355	3.71327	8.00000	.195313
5.13	26.3169	135.006	2.26495	7.16240	1.72467	3.71566	8.00520	.194932
5.14	26.4196	135.797	2.26716	7.16938	1.72579	3.71810	8.01040	.194553
5.15	26.5225	136.591	2.26936	7.17635	1.72691	3.72051	8.01559	.194175
5.16	26.6256	137.388	2.27156	7.18331	1.72802	3.72292	8.02078	.193798
5.17	26.7289	138.188	2.27376	7.19027	1.72914	3.72532	8.02596	.193424
5.18	26.8324	138.992	2.27596	7.19722	1.73025	3.72772	8.03113	.193050
5.19	26.9361	139.798	2.27816	7.20417	1.73137	3.73012	8.03629	.192678
5.20	27.0400	140.608	2.28035	7.21110	1.73248	3.73251	8.04145	.192308
5.21	27.1441	141.421	2.28254	7.21803	1.73359	3.73490	8.04660	.191939
5.22	27.2484	142.237	2.28473	7.22496	1.73470	3.73729	8.05175	.191571
5.23	27.3529	143.056	2.28692	7.23187	1.73580	3.73968	8.05689	.191205
5.24	27.4576	143.878	2.28910	7.23878	1.73691	3.74206	8.06202	.190840
5.25	27.5625	144.703	2.29129	7.24569	1.73801	3.74443	8.06714	.190476
5.26	27.6676	145.532	2.29347	7.25259	1.73912	3.74681	8.07226	.190114
5.27	27.7729	146.363	2.29565	7.25948	1.74022	3.74918	8.07737	.189753
5.28	27.8784	147.198	2.29783	7.26636	1.74132	3.75158	8.08248	.189394
5.29	27.9841	148.036	2.30000	7.27324	1.74242	3.75392	8.08758	.189036
5.30	28.0900	148.877	2.30217	7.28011	1.74351	3.75629	8.09267	.188679
5.31	28.1961	149.721	2.30434	7.28697	1.74461	3.75865	8.09776	.188324
5.32	28.3024	150.569	2.30651	7.29383	1.74570	3.76100	8.10284	.187970
5.33	28.4089	151.419	2.30868	7.30068	1.74680	3.76336	8.10791	.187617
5.34	28.5156	152.273	2.31084	7.30753	1.74789	3.76571	8.11298	.187266
5.35	28.6225	153.130	2.31301	7.31437	1.74898	3.76806	8.11804	.186916
5.36	28.7296	153.991	2.31517	7.32120	1.75007	3.77041	8.12310	.186567
5.37	28.8369	154.854	2.31733	7.32803	1.75116	3.77275	8.12814	.186220
5.38	28.9444	155.721	2.31948	7.33485	1.75224	3.77509	8.13319	.185874
5.39	29.0521	156.591	2.32164	7.34166	1.75333	3.77740	8.13822	.185529
5.40	29.1600	157.464	2.32379	7.34847	1.75441	3.77976	8.14325	.185185
5.41	29.2681	158.340	2.32594	7.35527	1.75549	3.78210	8.14828	.184843
5.42	29.3764	159.220	2.32809	7.36206	1.75657	3.78442	8.15329	.184502
5.43	29.4849	160.103	2.33024	7.36885	1.75765	3.78675	8.15831	.184162
5.44	29.5936	160.989	2.33238	7.37564	1.75873	3.78907	8.16331	.183824
5.45	29.7025	161.879	2.33452	7.38241	1.75981	3.79139	8.16831	.183486
5.46	29.8116	162.771	2.33666	7.38918	1.76088	3.79371	8.17330	.183150
5.47	29.9209	163.667	2.33880	7.39594	1.76196	3.79603	8.17829	.182815
5.48	30.0304	164.567	2.34094	7.40270	1.76303	3.79834	8.18327	.182482
5.49	30.1401	165.469	2.34307	7.40945	1.76410	3.80065	8.18824	.182149
5.50	30.2500	166.375	2.34521	7.41620	1.76517	3.80295	8.19321	.181818

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
5.51	30.3601	167.284	2.34734	7.42294	1.76624	3.80526	8.19818	.181488
5.52	30.4704	168.197	2.34947	7.42967	1.76731	3.80756	8.20313	.181159
5.53	30.5809	169.112	2.35160	7.43640	1.76838	3.80986	8.20808	.180832
5.54	30.6916	170.031	2.35372	7.44312	1.76944	3.80115	8.21303	.180505
5.55	30.8025	170.954	2.35584	7.44983	1.77051	3.81444	8.21797	.180180
5.56	30.9136	171.880	2.35797	7.45654	1.77157	3.81673	8.22290	.179856
5.57	31.0249	172.809	2.36008	7.46324	1.77263	3.81902	8.22783	.179533
5.58	31.1364	173.741	2.36220	7.46994	1.77369	3.82130	8.23275	.179212
5.59	31.2481	174.677	2.36432	7.47663	1.77475	3.82358	8.23766	.178891
5.60	31.3600	175.616	2.36643	7.48331	1.77581	3.82586	8.24257	.178571
5.61	31.4721	176.558	2.36854	7.48999	1.77686	3.82814	8.24747	.178253
5.62	31.5844	177.504	2.37065	7.49667	1.77792	3.83041	8.25237	.177936
5.63	31.6969	178.454	2.37276	7.50333	1.77897	3.83268	8.25726	.177620
5.64	31.8096	179.406	2.37487	7.50999	1.78003	3.83495	8.26215	.177305
5.65	31.9225	180.362	2.37697	7.51665	1.78108	3.83721	8.26703	.176991
5.66	32.0356	181.321	2.37908	7.52330	1.78213	3.83948	8.27190	.176678
5.67	32.1489	182.284	2.38118	7.52994	1.78318	3.84174	8.27677	.176367
5.68	32.2624	183.250	2.38328	7.53658	1.78422	3.84400	8.28164	.176056
5.69	32.3761	184.220	2.38537	7.54321	1.78527	3.84625	8.28649	.175747
5.70	32.4900	185.193	2.38747	7.54983	1.78632	3.84850	8.29134	.175439
5.71	32.6041	186.169	2.38956	7.55645	1.78736	3.85075	8.29619	.175131
5.72	32.7184	187.149	2.39165	7.56307	1.78840	3.85300	8.30103	.174825
5.73	32.8329	188.133	2.39374	7.56968	1.78944	3.85524	8.30587	.174520
5.74	32.9476	189.119	2.39583	7.57628	1.79048	3.85748	8.31069	.174216
5.75	33.0625	190.109	2.39792	7.58288	1.79152	3.85972	8.31552	.173913
5.76	33.1776	191.103	2.40000	7.58947	1.79256	3.86196	8.32034	.173611
5.77	33.2929	192.100	2.40208	7.59605	1.79360	3.86419	8.32515	.173310
5.78	33.4084	193.101	2.40416	7.60263	1.79463	3.86642	8.32995	.173010
5.79	33.5241	194.105	2.40624	7.60920	1.79567	3.86865	8.33476	.172712
5.80	33.6400	195.112	2.40832	7.61577	1.79670	3.87088	8.33955	.172414
5.81	33.7561	196.123	2.41039	7.62234	1.79773	3.87310	8.34434	.172117
5.82	33.8724	197.137	2.41247	7.62889	1.79876	3.87532	8.34913	.171821
5.83	33.9889	198.155	2.41454	7.63544	1.79979	3.87754	8.35390	.171527
5.84	34.1056	199.177	2.41661	7.64199	1.80082	3.87975	8.35868	.171233
5.85	34.2225	200.202	2.41868	7.64853	1.80185	3.88197	8.36345	.170940
5.86	34.3396	201.230	2.42074	7.65506	1.80288	3.88418	8.36821	.170649
5.87	34.4569	202.262	2.42281	7.66159	1.80390	3.88639	8.37297	.170358
5.88	34.5744	203.297	2.42487	7.66812	1.80492	3.88859	8.37772	.170068
5.89	34.6921	204.336	2.42693	7.67463	1.80595	3.89082	8.38247	.169779
5.90	34.8100	205.379	2.42899	7.68115	1.80697	3.89300	8.38721	.169492
5.91	34.9281	206.425	2.43105	7.68765	1.80799	3.89520	8.39194	.169205
5.92	35.0464	207.475	2.43311	7.69415	1.80901	3.89739	8.39667	.168919
5.93	35.1649	208.528	2.43516	7.70065	1.81003	3.89958	8.40140	.168634
5.94	35.2836	209.585	2.43721	7.70714	1.81104	3.90177	8.40612	.168350
5.95	35.4025	210.645	2.43926	7.71362	1.81206	3.90396	8.41083	.168067
5.96	35.5216	211.709	2.44131	7.72010	1.81307	3.90615	8.41554	.167785
5.97	35.6409	212.776	2.44336	7.72658	1.81409	3.90833	8.42025	.167504
5.98	35.7604	213.847	2.44540	7.73305	1.81510	3.91051	8.42494	.167224
5.99	35.8801	214.922	2.44745	7.73951	1.81611	3.91269	8.42964	.166945
6.00	36.0000	216.000	2.44949	7.74597	1.81712	3.91487	8.43433	.166667

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
6.01	36.1201	217.082	2.45153	7.75242	1.81813	3.91704	8.43901	.166389
6.02	36.2404	218.167	2.45357	7.75887	1.81914	3.91921	8.44369	.166113
6.03	36.3609	219.256	2.45561	7.76531	1.82014	3.92138	8.44836	.165838
6.04	36.4816	220.349	2.45764	7.77174	1.82115	3.92355	8.45303	.165563
6.05	36.6025	221.445	2.45967	7.77817	1.82215	3.92571	8.45769	.165289
6.06	36.7236	222.545	2.46171	7.78460	1.82316	3.92787	8.46235	.165017
6.07	36.8449	223.649	2.46374	7.79102	1.82416	3.93003	8.46700	.164745
6.08	36.9664	224.756	2.46577	7.79744	1.82516	3.93219	8.47165	.164474
6.09	37.0881	225.867	2.46779	7.80385	1.82616	3.93434	8.47629	.164204
6.10	37.2100	226.981	2.46982	7.81025	1.82716	3.93650	8.48093	.163934
6.11	37.3321	228.099	2.47184	7.81665	1.82816	3.93865	8.48556	.163666
6.12	37.4544	229.221	2.47386	7.82304	1.82915	3.94079	8.49018	.163399
6.13	37.5769	230.346	2.47588	7.82943	1.83015	3.94294	8.49481	.163132
6.14	37.6996	231.476	2.47790	7.83582	1.83115	3.94508	8.49942	.162866
6.15	37.8225	232.608	2.47992	7.84219	1.83214	3.94722	8.50404	.162602
6.16	37.9456	233.745	2.48193	7.84857	1.83313	3.94936	8.50864	.162338
6.17	38.0689	234.885	2.48395	7.85493	1.83412	3.95150	8.51324	.162075
6.18	38.1924	236.029	2.48596	7.86130	1.83511	3.95363	8.51784	.161812
6.19	38.3161	237.177	2.48797	7.86766	1.83610	3.95576	8.52243	.161551
6.20	38.4400	238.328	2.48998	7.87401	1.83709	3.95789	8.52702	.161290
6.21	38.5641	239.483	2.49199	7.88036	1.83808	3.96002	8.53160	.161031
6.22	38.6884	240.642	2.49399	7.88670	1.83906	3.96214	8.53618	.160772
6.23	38.8129	241.804	2.49600	7.89303	1.84005	3.96426	8.54075	.160514
6.24	38.9376	242.971	2.49800	7.89937	1.84103	3.96639	8.54532	.160256
6.25	39.0625	244.141	2.50000	7.90569	1.84202	3.96850	8.54988	.160000
6.26	39.1876	245.314	2.50200	7.91202	1.84300	3.97062	8.55444	.159744
6.27	39.3129	246.492	2.50400	7.91833	1.84398	3.97273	8.55899	.159490
6.28	39.4384	247.673	2.50599	7.92465	1.84496	3.97484	8.56354	.159236
6.29	39.5641	248.858	2.50799	7.93095	1.84594	3.97695	8.56808	.158983
6.30	39.6900	250.047	2.50998	7.93725	1.84691	3.97906	8.57262	.158730
6.31	39.8161	251.240	2.51197	7.94355	1.84789	3.98116	8.57715	.158479
6.32	39.9424	252.436	2.51396	7.94984	1.84887	3.98326	8.58168	.158228
6.33	40.0689	253.636	2.51595	7.95613	1.84984	3.98536	8.58620	.157978
6.34	40.1956	254.840	2.51794	7.96241	1.85082	3.98746	8.59072	.157729
6.35	40.3225	256.048	2.51992	7.96869	1.85179	3.98956	8.59524	.157480
6.36	40.4496	257.259	2.52190	7.97496	1.85276	3.99165	8.59975	.157233
6.37	40.5769	258.475	2.52389	7.98123	1.85373	3.99374	8.60425	.156986
6.38	40.7044	259.694	2.52587	7.98749	1.85470	3.99583	8.60875	.156740
6.39	40.8321	260.917	2.52784	7.99375	1.85567	3.99792	8.61325	.156495
6.40	40.9600	262.144	2.52982	8.00000	1.85664	4.00000	8.61774	.156250
6.41	41.0881	263.375	2.53180	8.00625	1.85760	4.00208	8.62222	.156006
6.42	41.2164	264.609	2.53377	8.01249	1.85857	4.00416	8.62671	.155763
6.43	41.3449	265.848	2.53574	8.01873	1.85953	4.00624	8.63118	.155521
6.44	41.4736	267.090	2.53772	8.02496	1.86050	4.00832	8.63566	.155280
6.45	41.6025	268.336	2.53969	8.03119	1.86146	4.01039	8.64012	.155039
6.46	41.7316	269.586	2.54165	8.03741	1.86242	4.01246	8.64459	.154799
6.47	41.8609	270.840	2.54362	8.04363	1.86338	4.01453	8.64904	.154560
6.48	41.9904	272.098	2.54558	8.04984	1.86434	4.01660	8.65350	.154321
6.49	42.1201	273.359	2.54755	8.05605	1.86530	4.01866	8.65795	.154083
6.50	42.2500	274.625	2.54951	8.06226	1.86626	4.02073	8.66239	.153846

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
6.51	42.3801	275.894	2.55147	8.06846	1.86721	4.02279	8.66683	.153610
6.52	42.5104	277.168	2.55343	8.07465	1.86817	4.02485	8.67127	.153374
6.53	42.6409	278.445	2.55539	8.08084	1.86912	4.02690	8.67570	.153139
6.54	42.7716	279.726	2.55734	8.08703	1.87008	4.02896	8.68012	.152905
6.55	42.9025	281.011	2.55930	8.09321	1.87103	4.03101	8.68455	.152672
6.56	43.0336	282.300	2.56125	8.09938	1.87198	4.03306	8.68896	.152439
6.57	43.1649	283.593	2.56320	8.10555	1.87293	4.03511	8.69338	.152207
6.58	43.2964	284.890	2.56515	8.11172	1.87388	4.03715	8.69778	.151976
6.59	43.4281	286.191	2.56710	8.11788	1.87483	4.03920	8.70219	.151745
6.60	43.5600	287.496	2.56905	8.12404	1.87578	4.04124	8.70659	.151515
6.61	43.6921	288.805	2.57099	8.13019	1.87672	4.04328	8.71098	.151286
6.62	43.8244	290.118	2.57294	8.13634	1.87767	4.04532	8.71537	.151057
6.63	43.9569	291.434	2.57488	8.14248	1.87862	4.04735	8.71976	.150830
6.64	44.0896	292.755	2.57682	8.14862	1.87956	4.04939	8.72414	.150602
6.65	44.2225	294.080	2.57876	8.15475	1.88050	4.05142	8.72852	.150376
6.66	44.3556	295.408	2.58070	8.16088	1.88144	4.05345	8.73289	.150150
6.67	44.4889	296.741	2.58263	8.16701	1.88239	4.05548	8.73726	.149925
6.68	44.6224	298.078	2.58457	8.17313	1.88333	4.05750	8.74162	.149701
6.69	44.7561	299.418	2.58650	8.17924	1.88427	4.05953	8.74598	.149477
6.70	44.8900	300.763	2.58844	8.18535	1.88520	4.06155	8.75034	.149254
6.71	45.0241	302.112	2.59037	8.19146	1.88614	4.06357	8.75469	.149031
6.72	45.1584	303.464	2.59230	8.19756	1.88708	4.06558	8.75904	.148810
6.73	45.2929	304.821	2.59422	8.20366	1.88801	4.06760	8.76338	.148588
6.74	45.4276	306.182	2.59615	8.20975	1.88895	4.06961	8.76772	.148368
6.75	45.5625	307.547	2.59808	8.21584	1.88988	4.07163	8.77205	.148148
6.76	45.6976	308.916	2.60000	8.22192	1.89081	4.07364	8.77638	.147929
6.77	45.8329	310.289	2.60192	8.22800	1.89175	4.07564	8.78071	.147711
6.78	45.9684	311.666	2.60384	8.23408	1.89268	4.07765	8.78503	.147493
6.79	46.1041	313.047	2.60576	8.24015	1.89361	4.07965	8.78935	.147275
6.80	46.2400	314.432	2.60768	8.24621	1.89454	4.08166	8.79366	.147059
6.81	46.3761	315.821	2.60960	8.25227	1.89546	4.08365	8.79797	.146843
6.82	46.5124	317.215	2.61151	8.25833	1.89639	4.08565	8.80227	.146628
6.83	46.6489	318.612	2.61343	8.26438	1.89732	4.08765	8.80657	.146413
6.84	46.7856	320.014	2.61534	8.27043	1.89824	4.08964	8.81087	.146199
6.85	46.9225	321.419	2.61725	8.27647	1.89917	4.09164	8.81516	.145985
6.86	47.0596	322.829	2.61916	8.28251	1.90009	4.09362	8.81945	.145773
6.87	47.1969	324.243	2.62107	8.28855	1.90102	4.09561	8.82373	.145560
6.88	47.3344	325.661	2.62298	8.29458	1.90194	4.09760	8.82801	.145349
6.89	47.4721	327.083	2.62488	8.30060	1.90286	4.09958	8.83229	.145138
6.90	47.6100	328.509	2.62679	8.30662	1.90378	4.10157	8.83656	.144928
6.91	47.7481	329.939	2.62869	8.31264	1.90470	4.10355	8.84082	.144718
6.92	47.8864	331.374	2.63059	8.31865	1.90562	4.10552	8.84509	.144509
6.93	48.0249	332.813	2.63249	8.32466	1.90653	4.10750	8.84934	.144300
6.94	48.1636	334.255	2.63439	8.33067	1.90745	4.10948	8.85360	.144092
6.95	48.3025	335.702	2.63629	8.33667	1.90837	4.11145	8.85785	.143885
6.96	48.4416	337.154	2.63818	8.34266	1.90928	4.11342	8.86210	.143678
6.97	48.5809	338.609	2.64008	8.34865	1.91019	4.11539	8.86634	.143472
6.98	48.7204	340.068	2.64197	8.35464	1.91111	4.11736	8.87058	.143267
6.99	48.8601	341.532	2.64386	8.36062	1.91202	4.11932	8.87481	.143062
7.00	49.0000	343.000	2.64575	8.36660	1.91293	4.12129	8.87904	.142857

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
7.01	49.1401	344.472	2.64764	8.37257	1.91384	4.12325	8.88327	.142653
7.02	49.2804	345.948	2.64953	8.37854	1.91475	4.12521	8.88749	.142450
7.03	49.4209	347.429	2.65141	8.38451	1.91566	4.12716	8.89171	.142248
7.04	49.5616	348.914	2.65330	8.39047	1.91657	4.12912	8.89592	.142046
7.05	49.7025	350.403	2.65518	8.39643	1.91747	4.13107	8.90013	.141844
7.06	49.8436	351.896	2.65707	8.40238	1.91838	4.13303	8.90434	.141643
7.07	49.9849	353.393	2.65895	8.40833	1.91929	4.13498	8.90854	.141443
7.08	50.1264	354.895	2.66083	8.41427	1.92019	4.13695	8.91274	.141243
7.09	50.2681	356.401	2.66271	8.42021	1.92109	4.13887	8.91693	.141044
7.10	50.4100	357.911	2.66458	8.42615	1.92200	4.14082	8.92112	.140845
7.11	50.5521	359.425	2.66646	8.43208	1.92290	4.14276	8.92531	.140647
7.12	50.6944	360.944	2.66833	8.43801	1.92380	4.14470	8.92949	.140449
7.13	50.8369	362.467	2.67021	8.44393	1.92470	4.14664	8.93367	.140253
7.14	50.9796	363.994	2.67208	8.44985	1.92560	4.14858	8.93784	.140056
7.15	51.1225	365.526	2.67395	8.45577	1.92650	4.15051	8.94201	.139860
7.16	51.2656	367.062	2.67582	8.46168	1.92740	4.15245	8.94618	.139665
7.17	51.4089	368.602	2.67769	8.46759	1.92829	4.15438	8.95034	.139470
7.18	51.5524	370.146	2.67955	8.47349	1.92919	4.15631	8.95450	.139276
7.19	51.6961	371.695	2.68142	8.47939	1.93008	4.15824	8.95866	.139082
7.20	51.8400	373.248	2.68328	8.48528	1.93098	4.16017	8.96281	.138889
7.21	51.9841	374.805	2.68514	8.49117	1.93187	4.16209	8.96696	.138696
7.22	52.1284	376.367	2.68701	8.49706	1.93277	4.16402	8.97110	.138504
7 23	52.2729	377.933	2.68887	8.50294	1.93366	4.16594	8.97524	.138313
7.24	52.4176	379.503	2.69072	8.50882	1.93455	4.16786	8.97938	.138122
7.25	52.5625	381.078	2.69258	8.51469	1.93544	4.16978	8.98351	.137931
7.26	52.7076	382.657	2.69444	8.52056	1.93633	4.17169	8.98764	.137741
7.27	52.8529	384.241	2.69629	8.52643	1.93722	4.17361	8.99176	.137552
7.28	52.9984	385.828	2.69815	8.53229	1.93810	4.17552	8.99588	.137363
7.29	53.1441	387.420	2.70000	8.53815	1.93899	4.17743	9.00000	.137174
7.30	53.2900	389.017	2.70185	8.54400	1.93988	4.17934	9.00411	.136986
7.31	53.4361	390.618	2.70370	8.54985	1.94076	4.18125	9.00822	.136799
7.32	53.5824	392.223	2.70555	8.55570	1.94165	4.18315	9.01233	.136612
7.33	53.7289	393.833	2.70740	8.56154	1.94253	4.18506	9.01643	.136426
7.34	53.8756	395.447	2.70924	8.56738	1.94341	4.18696	9.02053	.136240
7.35	54.0225	397.065	2.71109	8.57321	1.94430	4.18886	9.02462	.136054
7.36	54.1696	398.688	2.71293	8.57904	1.94518	4.19076	9.02871	.135870
7.37	54.3169	400.316	2.71477	8.58487	1.94606	4.19266	9.03280	.135685
7.38	54.4644	401.947	2.71662	8.59069	1.94694	4.19455	9.03689	.135501
7.39	54.6121	403.583	2.71846	8.59651	1.94782	4.19644	9.04097	.135318
7.40	54.7600	405.224	2.72029	8.60233	1.94870	4.19834	9.04504	.135135
7.41	54.9081	406.869	2.72213	8.60814	1.94957	4.20023	9.04911	.134953
7.42	55.0564	408.518	2.72397	8.61394	1.95045	4.20212	9.05318	.134771
7.43	55.2049	410.172	2.72580	8.61974	1.95132	4.20400	9.05725	.134590
7.44	55.3536	411.831	2.72764	8.62554	1.95220	4.20589	9.06131	.134409
7.45	55.5025	413.494	2.72947	8.63134	1.95307	4.20777	9.06537	.134228
7.46	55.6516	415.161	2.73130	8.63713	1.95395	4.20965	9.06942	.134048
7.47	55.8009	416.833	2.73313	8.64292	1.95482	4.21153	9.07347	.133869
7.48	55.9504	418.509	2.73496	8.64870	1.95569	4.21341	9.07752	.133690
7.49	56.1001	420.190	2.73679	8.65448	1.95656	4.21529	9.08156	.133511
7.50	56.2500	421.875	2.73861	8.66025	1.95743	4.21716	9.08560	.133333

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
7.51	56.4001	423.565	2.74044	8.66603	1.95830	4.21904	9.08964	**.133156**
7.52	56.5504	425.259	2.74226	8.67179	1.95917	4.22091	9.09367	**.132979**
7.53	56.7009	426.958	2.74408	8.67756	1.96004	4.22278	9.09770	**.132802**
7.54	56.8516	428.661	2.74591	8.68332	1.96091	4.22465	9.10173	**.132626**
7.55	57.0025	430.369	2.74773	8.68907	1.96177	4.22651	9.10575	**.132450**
7.56	57.1536	432.081	2.74955	8.69483	1.96264	4.22838	9.10977	**.132275**
7.57	57.3049	433.798	2.75136	8.70057	1.96350	4.23024	9.11378	**.132100**
7.58	57.4564	435.520	2.75318	8.70632	1.96437	4.23210	9.11779	**.131926**
7.59	57.6081	437.245	2.75500	8.71206	1.96523	4.23396	9.12180	**.131752**
7.60	57.7600	438.976	2.75681	8.71780	1.96610	4.23582	9.12581	**.131579**
7.61	57.9121	440.711	2.75862	8.72353	1.96696	4.23768	9.12981	**.131406**
7.62	58.0644	442.451	2.76043	8.72926	1.96782	4.23954	9.13380	**.131234**
7.63	58.2169	444.195	2.76225	8.73499	1.96868	4.24139	9.13780	**.131062**
7.64	58.3696	445.994	2.76405	8.74071	1.96954	4.24324	9.14179	**.130890**
7.65	58.5225	447.697	2.76586	8.74643	1.97040	4.24509	9.14577	**.130719**
7.66	58.6756	449.455	2.76767	8.75214	1.97126	4.24694	9.14976	**.130548**
7.67	58.8289	451.218	2.76948	8.75785	1.97211	4.24879	9.15374	**.130378**
7.68	58.9824	452.985	2.77128	8.76356	1.97297	4.25063	9.15771	**.130208**
7.69	59.1361	454.757	2.77308	8.76926	1.97383	4.25248	9.16169	**.130039**
7.70	59.2900	456.533	2.77489	8.77496	1.97468	4.25432	9.16566	**.129870**
7.71	59.4441	458.314	2.77669	8.78066	1.97554	4.25616	9.16962	**.129702**
7.72	59.5984	460.100	2.77849	8.78635	1.97639	4.25800	9.17359	**.129534**
7.73	59.7529	461.890	2.78029	8.79204	1.97724	4.25984	9.17754	**.129366**
7.74	59.9076	463.685	2.78209	8.79773	1.97809	4.26168	9.18150	**.129199**
7.75	60.0625	465.484	2.78388	8.80341	1.97895	4.26351	9.18545	**.129032**
7.76	60.2176	467.289	2.78568	8.80909	1.97980	4.26534	9.18940	**.128866**
7.77	60.3729	469.097	2.78747	8.81476	1.98065	4.26717	9.19335	**.128700**
7.78	60.5284	470.911	2.78927	8.82043	1.98150	4.26900	9.19729	**.128535**
7.79	60.6841	472.729	2.79106	8.82610	1.98234	4.27083	9.20123	**.128370**
7.80	60.8400	474.552	2.79285	8.83176	1.98319	4.27266	9.20516	**.128205**
7.81	60.9961	476.380	2.79464	8.83742	1.98404	4.27448	9.20910	**.128041**
7.82	61.1524	478.212	2.79643	8.84308	1.98489	4.27631	9.21303	**.127877**
7.83	61.3089	480.049	2.79821	8.84873	1.98573	4.27813	9.21695	**.127714**
7.84	61.4656	481.890	2.80000	8.85438	1.98658	4.27995	9.22087	**.127551**
7.85	61.6225	483.737	2.80179	8.86002	1.98742	4.28177	9.22479	**.127389**
7.86	61.7796	485.588	2.80357	8.86566	1.98826	4.28359	9.22871	**.127227**
7.87	61.9369	487.443	2.80535	8.87130	1.98911	4.28540	9.23262	**.127065**
7.88	62.0944	489.304	2.80713	8.87694	1.98995	4.28722	9.23653	**.126904**
7.89	62.2521	491.169	2.80891	8.88257	1.99079	4.28903	9.24043	**.126743**
7.90	62.4100	493.039	2.81069	8.88819	1.99163	4.29084	9.24433	**.126582**
7.91	62.5681	494.914	2.81247	8.89382	1.99247	4.29265	9.24823	**.126422**
7.92	62.7264	496.793	2.81425	8.89944	1.99331	4.29446	9.25213	**.126263**
7.93	62.8849	498.677	2.81603	8.90505	1.99415	4.29627	9.25602	**.126103**
7.94	63.0436	500.566	2.81780	8.91067	1.99499	4.29807	9.25991	**.125945**
7.95	63.2025	502.460	2.81957	8.91628	1.99582	4.29987	9.26380	**.125786**
7.96	63.3616	504.358	2.82135	8.92188	1.99666	4.30168	9.26768	**.125628**
7.97	63.5209	506.262	2.82312	8.92749	1.99750	4.30348	9.27156	**.125471**
7.98	63.6804	508.170	2.82489	8.93308	1.99833	4.30528	9.27544	**.125313**
7.99	63.8401	510.082	2.82666	8.93868	1.99917	4.30707	9.27931	**.125156**
8.00	64.0000	512.000	2.82843	8.94427	2.00000	4.30887	9.28318	**.125000**

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
8.01	64.1601	513.922	2.83019	8.94986	2.00083	4.31066	9.28704	.124844
8.02	64.3204	515.850	2.83196	8.95545	2.00167	4.31246	9.29091	.124688
8.03	64.4809	517.782	2.83373	8.96103	2.00250	4.31425	9.29477	.124533
8.04	64.6416	519.718	2.83549	8.96660	2.00333	4.31604	9.29862	.124378
8.05	64.8025	521.660	2.83725	8.97218	2.00416	4.31783	9.30248	.124224
8.06	64.9636	523.607	2.83901	8.97775	2.00499	4.31961	9.30633	.124070
8.07	65.1249	525.558	2.84077	8.98332	2.00582	4.32140	9.31018	.123916
8.08	65.2864	527.514	2.84253	8.98888	2.00664	4.32318	9.31402	.123762
8.09	65.4481	529.475	2.84429	8.99444	2.00747	4.32497	9.31786	.123609
8.10	65.6100	531.441	2.84605	9.00000	2.00830	4.32675	9.32170	.123457
8.11	65.7721	533.412	2.84781	9.00555	2.00912	4.32853	9.32553	.123305
8.12	65.9344	535.387	2.84956	9.01110	2.00995	4.33031	9.32936	.123153
8.13	66.0969	537.368	2.85132	9.01665	2.01078	4.33208	9.33319	.123001
8.14	66.2596	539.353	2.85307	9.02219	2.01160	4.33386	9.33702	.122850
8.15	66.4225	541.343	2.85482	9.02774	2.01242	4.33563	9.34084	.122699
8.16	66.5856	543.338	2.85657	9.03327	2.01325	4.33741	9.34466	.122549
8.17	66.7489	545.339	2.85832	9.03881	2.01407	4.33918	9.34847	.122399
8.18	66.9124	547.343	2.86007	9.04434	2.01489	4.34095	9.35229	.122249
8.19	67.0761	549.353	2.86182	9.04986	2.01571	4.34272	9.35610	.122100
8.20	67.2400	551.368	2.86356	9.05539	2.01653	4.34448	9.35990	.121951
8.21	67.4041	553.388	2.86531	9.06091	2.01735	4.34625	9.36370	.121803
8.22	67.5684	555.412	2.86705	9.06642	2.01817	4.34801	9.36751	.121655
8.23	67.7329	557.442	2.86880	9.07193	2.01899	4.34977	9.37130	.121507
8.24	67.8976	559.476	2.87054	9.07744	2.01980	4.35153	9.37510	.121359
8.25	68.0625	561.516	2.87228	9.08295	2.02062	4.35329	9.37889	.121212
8.26	68.2276	563.560	2.87402	9.08845	2.02144	4.35505	9.38268	.121065
8.27	68.3929	565.609	2.87576	9.09395	2.02225	4.35681	9.38646	.120919
8.28	68.5584	567.664	2.87750	9.09945	2.02307	4.35856	9.39024	.120773
8.29	68.7241	569.723	2.87924	9.10494	2.02388	4.36032	9.39402	.120627
8.30	68.8900	571.787	2.88097	9.11043	2.02469	4.36207	9.39780	.120482
8.31	69.0561	573.856	2.88271	9.11592	2.02551	4.36382	9.40157	.120337
8.32	69.2224	575.930	2.88444	9.12140	2.02632	4.36557	9.40534	.120192
8.33	69.3889	578.010	2.88617	9.12688	2.02713	4.36732	9.40911	.120048
8.34	69.5556	580.094	2.88791	9.13236	2.02794	4.36907	9.41287	.119904
8.35	69.7225	582.183	2.88964	9.13783	2.02875	4.37081	9.41663	.119761
8.36	69.8896	584.277	2.89137	9.14330	2.02956	4.37255	9.42039	.119617
8.37	70.0569	586.376	2.89310	9.14877	2.03037	4.37430	9.42414	.119474
8.38	70.2244	588.480	2.89482	9.15423	2.03118	4.37604	9.42789	.119332
8.39	70.3921	590.590	2.89655	9.15969	2.03199	4.37778	9.43164	.119190
8.40	70.5600	592.704	2.89828	9.16515	2.03279	4.37952	9.43539	.119048
8.41	70.7281	594.823	2.90000	9.17061	2.03360	4.38126	9.43913	.118906
8.42	70.8964	596.948	2.90172	9.17606	2.03440	4.38299	9.44287	.118765
8.43	71.0649	599.077	2.90345	9.18150	2.03521	4.38473	9.44661	.118624
8.44	71.2336	601.212	2.90517	9.18695	2.03601	4.38646	9.45034	.118483
8.45	71.4025	603.351	2.90689	9.19239	2.03682	4.38819	9.45407	.118343
8.46	71.5716	605.496	2.90861	9.19783	2.03762	4.38992	9.45780	.118203
8.47	71.7409	607.645	2.91033	9.20326	2.03842	4.39165	9.46152	.118064
8.48	71.9104	609.800	2.91204	9.20869	2.03923	4.39338	9.46525	.117925
8.49	72.0801	611.960	2.91376	9.21412	2.04003	4.39511	9.46897	.117786
8.50	72.2500	614.125	2.91548	9.21954	2.04083	4.39683	9.47268	.117647

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
8.51	72.4201	616.295	2.91719	9.22497	2.04163	4.39855	9.47640	.117509
8.52	72.5904	618.470	2.91890	9.23038	2.04243	4.40028	9.48011	.117371
8.53	72.7609	620.650	2.92062	9.23580	2.04323	4.40200	9.48381	.117233
8.54	72.9316	622.836	2.92233	9.24121	2.04402	4.40372	9.48752	.117096
8.55	73.1025	625.026	2.92404	9.24662	2.04482	4.40543	9.49122	.116959
8.56	73.2736	627.222	2.92575	9.25203	2.04562	4.40715	9.49492	.116822
8.57	73.4449	629.423	2.92746	9.25743	2.04641	4.40887	9.49861	.116686
8.58	73.6164	631.629	2.92916	9.26283	2.04721	4.41058	9.50231	.116550
8.59	73.7881	633.840	2.93087	9.26823	2.04801	4.41229	9.50600	.116414
8.60	73.9600	636.056	2.93258	9.27362	2.04880	4.41400	9.50969	.116279
8.61	74.1321	638.277	2.93428	9.27901	2.04959	4.41571	9.51337	.116144
8.62	74.3044	640.504	2.93598	9.28440	2.05039	4.41742	9.51705	.116009
8.63	74.4769	642.736	2.93769	9.28978	2.05118	4.41913	9.52073	.115875
8.64	74.6496	644.973	2.93939	9.29516	2.05197	4.42084	9.52441	.115741
8.65	74.8225	647.215	2.94109	9.30054	2.05276	4.42254	9.52808	.115607
8.66	74.9956	649.462	2.94279	9.30591	2.05355	4.42425	9.53175	.115473
8.67	75.1689	651.714	2.94449	9.31128	2.05434	4.42595	9.53542	.115340
8.68	75.3424	653.972	2.94618	9.31665	2.05513	4.42765	9.53908	.115207
8.69	75.5161	656.235	2.94788	9.32202	2.05592	4.42935	9.54274	.115075
8.70	75.6900	658.503	2.94958	9.32738	2.05671	4.43105	9.54640	.114943
8.71	75.8641	660.776	2.95127	9.33274	2.05750	4.43274	9.55006	.114811
8.72	76.0384	663.055	2.95296	9.33809	2.05828	4.43444	9.55371	.114679
8.73	76.2129	665.339	2.95466	9.34345	2.05907	4.43614	9.55736	.114548
8.74	76.3876	667.628	2.95635	9.34880	2.05986	4.43783	9.56101	.114417
8.75	76.5625	669.922	2.95804	9.35414	2.06064	4.43952	9.56466	.114286
8.76	76.7376	672.221	2.95973	9.35949	2.06143	4.44121	9.56830	.114155
8.77	76.9129	674.526	2.96142	9.36483	2.06221	4.44290	9.57194	.114025
8.78	77.0884	676.836	2.96311	9.37017	2.06299	4.44459	9.57557	.113895
8.79	77.2641	679.151	2.96479	9.37550	2.06378	4.44627	9.57921	.113766
8.80	77.4400	681.472	2.96648	9.38083	2.06456	4.44796	9.58284	.113636
8.81	77.6161	683.798	2.96816	9.38616	2.06534	4.44964	9.58647	.113507
8.82	77.7924	686.129	2.96985	9.39149	2.06612	4.45133	9.59009	.113379
8.83	77.9689	688.465	2.97153	9.39681	2.06690	4.45301	9.59372	.113250
8.84	78.1456	690.807	2.97321	9.40213	2.06768	4.45469	9.59734	.113122
8.85	78.3225	693.154	2.97489	9.40744	2.06846	4.45637	9.60095	.112994
8.86	78.4996	695.506	2.97658	9.41276	2.06924	4.45805	9.60457	.112867
8.87	78.6769	697.864	2.97825	9.41807	2.07002	4.45972	9.60818	.112740
8.88	78.8544	700.227	2.97993	9.42338	2.07080	4.46140	9.61179	.112613
8.89	79.0321	702.595	2.98161	9.42868	2.07157	4.46307	9.61540	.112486
8.90	79.2100	704.969	2.98329	9.43398	2.07235	4.46474	9.61900	.112360
8.91	79.3881	707.348	2.98496	9.43928	2.07313	4.46642	9.62260	.112233
8.92	79.5664	709.732	2.98664	9.44458	2.07390	4.46809	9.62620	.112108
8.93	79.7449	712.122	2.98831	9.44987	2.07468	4.46976	9.62980	.111982
8.94	79.9236	714.517	2.98998	9.45516	2.07545	4.47142	9.63339	.111857
8.95	80.1025	716.917	2.99166	9.46044	2.07622	4.47309	9.63698	.111732
8.96	80.2816	719.323	2.99333	9.46573	2.07700	4.47476	9.64057	.111607
8.97	80.4609	721.734	2.99500	9.47101	2.07777	4.47642	9.64415	.111483
8.98	80.6404	724.151	2.99666	9.47629	2.07854	4.47808	9.64774	.111359
8.99	80.8201	726.573	2.99833	9.48156	2.07931	4.47974	9.65132	.111235
9.00	81.0000	729.000	3.00000	9.48683	2.08008	4.48140	9.65489	.111111

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
9.01	81.1801	731.433	3.00167	9.49210	2.08085	4.48306	9.65847	**.110988**
9.02	81.3604	733.871	3.00333	9.49737	2.08162	4.48472	9.66204	**.110865**
9.03	81.5409	736.314	3.00500	9.50263	2.08239	4.48638	9.66561	**.110742**
9.04	81.7216	738.763	3.00666	9.50789	2.08316	4.48803	9.66918	**.110620**
9.05	81.9025	741.218	3.00832	9.51315	2.08393	4.48968	9.67274	**.110497**
9.06	82.0836	743.677	3.00998	9.51840	2.08470	4.49134	9.67630	**.110375**
9.07	82.2649	746.143	3.01164	9.52365	2.08546	4.49299	9.67986	**.110254**
9.08	82.4464	748.613	3.01330	9.52890	2.08623	4.49464	9.68342	**.110132**
9.09	82.6281	751.089	3.01496	9.53415	2.08699	4.49629	9.68697	**.110011**
9.10	82.8100	753.571	3.01662	9.53939	2.08776	4.49794	9.69052	**.109890**
9.11	82.9921	756.058	3.01828	9.54463	2.08852	4.49959	9.69407	**.109770**
9.12	83.1744	758.551	3.01993	9.54987	2.08929	4.50123	9.69762	**.109649**
9.13	83.3569	761.048	3.02159	9.55510	2.09005	4.50288	9.70116	**.109529**
9.14	83.5396	763.552	3.02324	9.56033	2.09081	4.50452	9.70470	**.109409**
9.15	83.7225	766.061	3.02490	9.56556	2.09158	4.50616	9.70824	**.109290**
9.16	83.9056	768.575	3.02655	9.57079	2.09234	4.50780	9.71177	**.109170**
9.17	84.0889	771.095	3.02820	9.57601	2.09310	4.50945	9.71531	**.109051**
9.18	84.2724	773.621	3.02985	9.58123	2.09386	4.51108	9.71884	**.108933**
9.19	84.4561	776.152	3.03150	9.58645	2.09462	4.51272	9.72236	**.108814**
9.20	84.6400	778.688	3.03315	9.59166	2.09538	4.51436	9.72589	**.108696**
9.21	84.8241	781.230	3.03480	9.59687	2.09614	4.51599	9.72941	**.108578**
9.22	85.0084	783.777	3.03645	9.60208	2.09690	4.51763	9.73293	**.108460**
9.23	85.1929	786.330	3.03809	9.60729	2.09765	4.51926	9.73645	**.108342**
9.24	85.3776	788.889	3.03974	9.61249	2.09841	4.52089	9.73996	**.108225**
9.25	85.5625	791.453	3.04138	9.61769	2.09917	4.52252	9.74348	**.108108**
9.26	85.7476	794.023	3.04302	9.62289	2.09992	4.52415	9.74699	**.107991**
9.27	85.9329	796.598	3.04467	9.62808	2.10068	4.52578	9.75049	**.107875**
9.28	86.1184	799.179	3.04631	9.63328	2.10144	4.52740	9.75400	**.107759**
9.29	86.3041	801.765	3.04795	9.63846	2.10219	4.52903	9.75750	**.107643**
9.30	86.4900	804.357	3.04959	9.64365	2.10294	4.53065	9.76100	**.107527**
9.31	86.6761	806.954	3.05123	9.64883	2.10370	4.53228	9.76450	**.107411**
9.32	86.8624	809.558	3.05287	9.65401	2.10445	4.53390	9.76799	**.107296**
9.33	87.0489	812.166	3.05450	9.65919	2.10520	4.53552	9.77148	**.107181**
9.34	87.2356	814.781	3.05614	9.66437	2.10595	4.53714	9.77497	**.107066**
9.35	87.4225	817.400	3.05778	9.66954	2.10671	4.53876	9.77846	**.106952**
9.36	87.6096	820.026	3.05941	9.67471	2.10746	4.54038	9.78195	**.106838**
9.37	87.7969	822.657	3.06105	9.67988	2.10821	4.54199	9.78543	**.106724**
9.38	87.9844	825.294	3.06268	9.68504	2.10896	4.54361	9.78891	**.106610**
9.39	88.1721	827.936	3.06431	9.69020	2.10971	4.54522	9.79239	**.106496**
9.40	88.3600	830.584	3.06594	9.69536	2.11045	4.54634	9.79586	**.106383**
9.41	88.5481	833.238	3.06757	9.70052	2.11120	4.54845	9.79933	**.106270**
9.42	88.7364	835.897	3.06920	9.70567	2.11195	4.55006	9.80280	**.106157**
9.43	88.9249	838.562	3.07083	9.71082	2.11270	4.55167	9.80627	**.106045**
9.44	89.1136	841.232	3.07246	9.71597	2.11344	4.55328	9.80974	**.105932**
9.45	89.3025	843.909	3.07409	9.72111	2.11419	4.55488	9.81320	**.105820**
9.46	89.4916	846.591	3.07571	9.72625	2.11494	4.55649	9.81666	**.105708**
9.47	89.6809	849.278	3.07734	9.73139	2.11568	4.55809	9.82012	**.105597**
9.48	89.8704	851.971	3.07896	9.73653	2.11642	4.55970	9.82357	**.105485**
9.49	90.0601	854.670	3.08058	9.74166	2.11717	4.56130	9.82703	**.105374**
9.50	90.2500	857.375	3.08221	9.74679	2.11791	4.56290	9.83048	**.105263**

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
9.51	90.4401	860.085	3.08383	9.75192	2.11865	4.56450	9.83392	.105153
9.52	90.6304	862.801	3.08545	9.75705	2.11940	4.56610	9.83737	.105042
9.53	90.8209	865.523	3.08707	9.76217	2.12014	4.56770	9.84081	.104932
9.54	91.0116	868.251	3.08869	9.76729	2.12088	4.56930	9.84425	.104822
9.55	91.2025	870.984	3.09031	9.77241	2.12162	4.57089	9.84769	.104712
9.56	91.3936	873.723	3.09192	9.77753	2.12236	4.57249	9.85113	.104603
9.57	91.5849	876.467	3.09354	9.78264	2.12310	4.57408	9.85456	.104493
9.58	91.7764	879.218	3.09516	9.78775	2.12384	4.57568	9.85799	.104384
9.59	91.9681	881.974	3.09677	9.79285	2.12458	4.57727	9.86142	.104275
9.60	92.1600	884.736	3.09839	9.79796	2.12532	4.57886	9.86485	.104167
9.61	92.3521	887.504	3.10000	9.80306	2.12605	4.58045	9.86827	.104058
9.62	92.5444	890.277	3.10161	9.80816	2.12679	4.58203	9.87169	.103950
9.63	92.7369	893.056	3.10322	9.81326	2.12753	4.58362	9.87511	.103842
9.64	92.9296	895.841	3.10483	9.81835	2.12826	4.58521	9.87853	.103734
9.65	93.1225	898.632	3.10644	9.82344	2.12900	4.58679	9.88195	.103627
9.66	93.3156	901.429	3.10805	9.82853	2.12974	4.58838	9.88536	.103520
9.67	93.5089	904.231	3.10966	9.83362	2.13047	4.58996	9.88877	.103413
9.68	93.7024	907.039	3.11127	9.83870	2.13120	4.59154	9.89217	.103306
9.69	93.8961	909.853	3.11288	9.84378	2.13194	4.59312	9.89558	.103199
9.70	94.0900	912.673	3.11448	9.84886	2.13267	4.59470	9.89898	.103093
9.71	94.2841	915.499	3.11609	9.85393	2.13340	4.59628	9.90238	.102987
9.72	94.4784	918.330	3.11769	9.85901	2.13414	4.59786	9.90578	.102881
9.73	94.6729	921.167	3.11929	9.86408	2.13487	4.59943	9.90918	.102775
9.74	94.8676	924.010	3.12090	9.86914	2.13560	4.60101	9.91257	.102669
9.75	95.0625	926.859	3.12250	9.87421	2.13633	4.60258	9.91596	.102564
9.76	95.2576	929.714	3.12410	9.87927	2.13706	4.60416	9.91935	.102459
9.77	95.4529	932.575	3.12570	9.88433	2.13779	4.60573	9.92274	.102354
9.78	95.6484	935.441	3.12730	9.88939	2.13852	4.60730	9.92612	.102250
9.79	95.8441	938.314	3.12890	9.89444	2.13925	4.60887	9.92950	.102145
9.80	96.0400	941.192	3.13050	9.89949	2.13997	4.61044	9.93288	.102041
9.81	96.2361	944.076	3.13209	9.90454	2.14070	4.61200	9.93626	.101937
9.82	96.4324	946.966	3.13369	9.90959	2.14143	4.61357	9.93964	.101833
9.83	96.6289	949.862	3.13528	9.91464	2.14216	4.61513	9.94301	.101729
9.84	96.8256	952.764	3.13688	9.91968	2.14288	4.61670	9.94638	.101626
9.85	97.0225	955.672	3.13847	9.92472	2.14361	4.61826	9.94975	.101523
9.86	97.2196	958.585	3.14006	9.92975	2.14433	4.61983	9.95311	.101420
9.87	97.4169	961.505	3.14166	9.93479	2.14506	4.62139	9.95648	.101317
9.88	97.6144	964.430	3.14325	9.93982	2.14578	4.62295	9.95984	.101215
9.89	97.8121	967.362	3.14484	9.94485	2.14651	4.62451	9.96320	.101112
9.90	98.0100	970.299	3.14643	9.94987	2.14723	4.62607	9.96655	.101010
9.91	98.2081	973.242	3.14802	9.95490	2.14795	4.62762	9.96991	.100908
9.92	98.4064	976.191	3.14960	9.95992	2.14867	4.62918	9.97326	.100807
9.93	98.6049	979.147	3.15119	9.96494	2.14940	4.63073	9.97661	.100705
9.94	98.8036	982.108	3.15278	9.96995	2.15012	4.63229	9.97996	.100604
9.95	99.0025	985.075	3.15436	9.97497	2.15084	4.63384	9.98331	.100503
9.96	99.2016	988.048	3.15595	9.97998	2.15156	4.63539	9.98665	.100402
9.97	99.4009	991.027	3.15753	9.98499	2.15228	4.63694	9.98999	.100301
9.98	99.6004	994.012	3.15911	9.98999	2.15300	4.63849	9.99333	.100200
9.99	99.8001	997.003	3.16070	9.99500	2.15372	4.64004	9.99667	.100100
10.00	100.000	1000.00	3.16228	10.0000	2.15443	4.64159	10.0000	.100000

DECIMAL EQUIVALENTS OF 64ths.

The decimal fractions printed in Roman give the value of the corresponding fraction to the fourth decimal place. A given decimal fraction is rarely exactly equal to one of these values, and the numbers in *Italic* show which common fraction is nearest to the given decimal. Thus, lay off the fraction .1330 in 64ths. The nearest decimal fractions are .1250 and .1406. The value of any fraction in Italic is the mean of the two adjacent fractions. In this instance, the mean fraction is .1328, and as .1330 is greater than this, .1406 or $\frac{9}{64}$ will be chosen. In the same manner the nearest 64ths corresponding to the decimal fractions .3670 and .8979 are found to be $\frac{23}{64}$ and $\frac{57}{64}$, respectively.

Fraction	Decimal	Fraction	Decimal	Fraction	Decimal	Fraction	Decimal
	.0078		*.2578*		*.5078*		*.7578*
$\frac{1}{64}$	.0156	$\frac{17}{64}$	.2656	$\frac{33}{64}$	.5156	$\frac{49}{64}$	.7656
	.0235		*.2735*		*.5235*		*.7735*
$\frac{1}{32}$	.0313	$\frac{9}{32}$	.2813	$\frac{17}{32}$	.5313	$\frac{25}{32}$	.7813
	.0391		*.2891*		*.5391*		*.7891*
$\frac{3}{64}$	.0469	$\frac{19}{64}$	.2969	$\frac{35}{64}$	.5469	$\frac{51}{64}$	.7969
	.0547		*.3047*		*.5547*		*.8047*
$\frac{1}{16}$	.0625	$\frac{5}{16}$	.3125	$\frac{9}{16}$	.5625	$\frac{13}{16}$	.8125
	.0703		*.3203*		*.5703*		*.8203*
$\frac{5}{64}$	.0781	$\frac{21}{64}$	.3281	$\frac{37}{64}$	.5781	$\frac{53}{64}$	.8281
	0860		*.3360*		*.5860*		*.8360*
$\frac{3}{32}$	.0938	$\frac{11}{32}$	.3438	$\frac{19}{32}$	.5938	$\frac{27}{32}$	.8438
	.1016		*.3516*		*.6016*		*.8516*
$\frac{7}{64}$	.1094	$\frac{23}{64}$	.3594	$\frac{39}{64}$	.6094	$\frac{55}{64}$	.8594
	.1172		*.3672*		*.6172*		*.8672*
$\frac{1}{8}$	.1250	$\frac{3}{8}$	.3750	$\frac{5}{8}$	.6250	$\frac{7}{8}$	.8750
	.1328		*.3828*		*.6328*		*.8828*
$\frac{9}{64}$	.1406	$\frac{25}{64}$	.3906	$\frac{41}{64}$	.6406	$\frac{57}{64}$	.8906
	.1485		*.3985*		*.6485*		*.8985*
$\frac{5}{32}$	.1563	$\frac{13}{32}$	.4063	$\frac{21}{32}$	.6563	$\frac{29}{32}$	.9063
	.1641		*.4141*		*.6641*		*.9141*
$\frac{11}{64}$	.1719	$\frac{27}{64}$	.4219	$\frac{43}{64}$	.6719	$\frac{59}{64}$	.9219
	.1797		*.4297*		*.6797*		*.9297*
$\frac{3}{16}$	.1875	$\frac{7}{16}$	.4375	$\frac{11}{16}$	.6875	$\frac{15}{16}$	.9375
	.1953		*.4453*		*.6953*		*.9453*
$\frac{13}{64}$	.2031	$\frac{29}{64}$	.4531	$\frac{45}{64}$	.7031	$\frac{61}{64}$	.9531
	.2110		*.4610*		*.7110*		*.9610*
$\frac{7}{32}$	.2188	$\frac{15}{32}$	.4688	$\frac{23}{32}$	.7188	$\frac{31}{32}$	.9688
	.2266		*.4766*		*.7266*		*.9766*
$\frac{15}{64}$	.2344	$\frac{31}{64}$	.4844	$\frac{47}{64}$	.7344	$\frac{63}{64}$	.9844
	.2422		*.4922*		*.7422*		*.9922*
$\frac{1}{4}$	.2500	$\frac{1}{2}$	.5000	$\frac{3}{4}$	.7500	1	1.0000
	.2578		*.5078*		*.7578*		*1.0078*

DECIMALS OF A FOOT FOR EACH 1-32 IN.

In.	0″	1″	2″	3″	4″	5″	6″	7″	8″	9″	10″	11″
0	0	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500	.8333	.9167
$\frac{1}{32}$	.0026	.0859	.1693	.2526	.3359	.4193	.5026	.5859	.6693	.7526	.8359	.9193
$\frac{1}{16}$	.0052	.0885	.1719	.2552	.3385	.4219	.5052	.5885	.6719	.7552	.8385	.9219
$\frac{3}{32}$	.0078	.0911	.1745	.2578	.3411	.4245	.5078	.5911	.6745	.7578	.8411	9245
$\frac{1}{8}$	.0104	.0937	.1771	.2604	.3437	.4271	.5104	.5937	.6771	.7604	.8437	.9271
$\frac{5}{32}$	.0130	.0964	.1797	.2630	.3464	.4297	.5130	.5964	.6797	.7630	.8464	.9297
$\frac{3}{16}$	.0156	.0990	.1823	.2656	.3490	.4323	.5156	.5990	.6823	.7656	.8490	.9323
$\frac{7}{32}$	.0182	.1016	.1849	.2682	.3516	.4349	.5182	.6016	.6849	.7682	.8516	.9349
$\frac{1}{4}$	.0208	.1042	.1875	.2708	.3542	.4375	.5208	.6042	.6875	.7708	.8542	.9375
$\frac{9}{32}$	.0234	.1068	.1901	.2734	.3568	.4401	.5234	.6068	.6901	.7734	.8568	.9401
$\frac{5}{16}$	.0260	.1094	.1927	.2760	.3594	.4427	.5260	.6094	.6927	.7760	.8594	.9427
$\frac{11}{32}$	.0286	.1120	.1953	.2786	.3620	.4453	.5286	.6120	.6953	.7786	.8620	.9453
$\frac{3}{8}$	.0312	.1146	.1979	.2812	.3646	.4479	.5312	.6146	.6979	.7812	.8646	.9479
$\frac{13}{32}$	.0339	.1172	.2005	.2839	.3672	.4505	.5339	.6172	.7005	.7839	.8672	.9505
$\frac{7}{16}$	.0365	.1198	.2031	.2865	.3698	.4531	.5365	.6198	.7031	.7865	.8698	.9531
$\frac{15}{32}$	.0391	.1224	.2057	.2891	.3724	.4557	.5391	.6224	.7057	.7891	.8724	.9557
$\frac{1}{2}$	.0417	.1250	.2083	.2917	.3750	.4583	.5417	.6250	.7083	.7917	.8750	.9583
$\frac{17}{32}$	.0443	.1276	.2109	.2943	.3776	.4609	.5443	.6276	.7109	.7943	.8776	.9609
$\frac{9}{16}$	.0469	.1302	.2135	.2969	.3802	.4635	.5469	.6302	.7135	.7969	.8802	.9635
$\frac{19}{32}$	.0495	.1328	.2161	.2995	.3828	.4661	.5495	.6328	.7161	.7995	.8828	.9661
$\frac{5}{8}$	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021	.8854	.9688
$\frac{21}{32}$	.0547	.1380	.2214	.3047	.3880	.4714	.5547	.6380	.7214	.8047	9880	.9714
$\frac{11}{16}$	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073	.8906	.9740
$\frac{23}{32}$	.0599	.1432	.2266	.3099	.3932	.4766	.5599	.6432	.7266	.8099	.8932	.9766
$\frac{3}{4}$	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125	.8958	.9792
$\frac{25}{32}$	.0651	.1484	.2318	.3151	.3984	.4818	.5651	.6484	.7318	.8151	.8984	.9818
$\frac{13}{16}$	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177	.9010	.9844
$\frac{27}{32}$	.0703	.1536	.2370	.3203	.4036	.4870	.5703	.6536	.7370	.8203	.9036	.9870
$\frac{7}{8}$	.0729	.1562	.2396	.3229	.4062	.4896	.5729	.6562	.7396	.8229	.9062	.9896
$\frac{29}{32}$	.0755	.1589	.2422	.3255	.4089	.4922	.5755	.6589	.7422	.8255	.9089	.9922
$\frac{15}{16}$	.0781	.1615	.2448	.3281	.4115	.4948	.5781	.6615	.7448	.8281	.9115	.9948
$\frac{31}{32}$	.0807	.1641	.2474	.3307	.4141	.4974	.5807	.6641	.7474	.8307	.9141	.9974

WEIGHTS AND MEASURES

LINEAR MEASURE

12 inches (in.) .... = 1 foot .... ft.
3 feet .... = 1 yard .... yd.
5½ yards .... = 1 rod .... rd.
40 rods .... = 1 furlong .... fur.
8 furlongs .... = 1 mile .... mi.

in.	*ft.*	*yd.*	*rd.*	*fur.*	*mi.*
36 =	3 =	1			
198 =	16½ =	5½ =	1		
7,920 =	660 =	220 =	40 =	1	
63,360 =	5,280 =	1,760 =	320 =	8 =	1

SURVEYOR'S MEASURE

7.92 inches .... = 1 link .... li.
25 links .... = 1 rod .... rd.
4 rods = 100 links = 66 feet... = 1 chain .... ch.
80 chains .... = 1 mile .... mi.

mi.	*ch.*	*rd.*	*li.*	*in.*
1 =	80 =	320 =	8,000 =	63,360

SQUARE MEASURE

144 square inches (sq. in.)..... = 1 square foot .... sq. ft.
9 square feet .... = 1 square yard .... sq. yd.
30¼ square yards .... = 1 square rod .... sq. rd.
160 square rods .... = 1 acre .... A.
640 acres .... = 1 square mile .... sq. mi.

sq. mi.	*A.*	*sq. rd.*	*sq. yd.*	*sq. ft.*	*sq. in.*
1 =	640 =	102,400 =	3,097,600 =	27,878,400 =	4,014,489,600

SURVEYOR'S SQUARE MEASURE

625 square links (sq. li.) ...... = 1 square rod .... sq. rd.
16 square rods .... = 1 square chain .... sq. ch.
10 square chains .... = 1 acre .... A.
40 acres .... = 1 square mile .... sq. mi.
36 square miles (6 mi. square) = 1 township .... Tp.

sq. mi.	*A.*	*sq. ch.*	*sq. rd.*	*sq. li.*
1 =	640 =	6,400 =	102,400 =	64,000,000

The acre contains 4,840 sq. yd., or 43,560 sq. ft., and in form of a square is 208.71 ft. on a side.

CUBIC MEASURE

1,728 cubic inches (cu. in.) .. = 1 cubic foot .... cu. ft.
27 cubic feet .... = 1 cubic yard.......... cu. yd.
128 cubic feet .... = 1 cord................. cd.
$24\frac{3}{4}$ cubic feet .... = 1 perch .... P.

cu. yd. *cu. ft.* *cu. in.*
1 = 27 = 46,656

MEASURE OF ANGLES OR ARCS

60 seconds (″) .... = 1 minute .... ′
60 minutes .... = 1 degree................. °
90 degrees .... = 1 rt. angle or quadrant.... ☐
360 degrees .... = 1 circle .... cir.

1 cir. = 360° = 21,600′ = 1,296,000″

AVOIRDUPOIS WEIGHT

$437\frac{1}{2}$ grains (gr.) .... = 1 ounce................. oz.
16 ounces .... = 1 pound .... lb.
100 pounds................ = 1 hundredweight .... cwt.
20 hundredweight or 2,000 lb = 1 ton .... T.

T. *cwt.* *lb.* *oz.* *gr.*
1 = 20 = 2,000 = 32,000 = 14,000,000

The avoirdupois pound contains 7,000 grains.

LONG TON TABLE

16 ounces .... = 1 pound .... lb.
112 pounds................. = 1 hundredweight .... cwt.
20 hundredweight, or 2,240 lb. = 1 ton .... T.

TROY WEIGHT

24 grains (gr.)............... = 1 pennyweight .... pwt.
20 pennyweights............. = 1 ounce .... oz.
12 ounces .... = 1 pound................. lb.

lb. *oz.* *pwt.* *gr.*
1 = 12 = 240 = 5,760

DRY MEASURE

2 pints (pt.) .... = 1 quart................. qt.
8 quarts.................... = 1 peck .... pk.
4 pecks...................... = 1 bushel................ bu.

bu. *pk.* *qt.* *pt.*
1 = 4 = 32 = 64

The *U. S. struck bushel* contains 2,150.42 cu. in. = 1.2444 cu. ft. Its dimensions are, by law, 18½ in. in diameter and 8 in. deep.

The *heaped bushel* is equal to 1¼ struck bushels, the cone being 6 in. high.

For approximations, the bushel may be taken at 1¼ cu. ft.; or 1 cu. ft. may be considered ⅘ bu.

The *British bushel* contains 2,218.19 cu. in. = 1.2837 cu. ft. = 1.032 U. S. bushels.

The *dry gallon* contains 268.8 cu. in., being ⅛ bu.

LIQUID MEASURE

4	gills (gi.)	= 1 pint	pt.
2	pints	= 1 quart	qt.
4	quarts	= 1 gallon	gal.
31½	gallons	= 1 barrel	bbl.
2	barrels, or 63 gallons	= 1 hogshead	hhd.

hhd.		*bbl.*		*gal.*		*qt.*		*pt.*		*gi.*
1	=	2	=	63	=	252	=	504	=	2,016

The *U. S. gallon* contains 231 cu. in. = .134 cu. ft., nearly; or 1 cu. ft. contains 7.48 gal.

The following cylinders contain the given measures very closely:

	Diam. Inches	*Height Inches*		*Diam. Inches*	*Height Inches*
Gill	1¾	3	Gallon	7	6
Pint	3½	3	8 gallons	14	12
Quart	3½	6	10 gallons	14	15

With water at its maximum density 1 cu. ft. weighs 62.425 lb. and 1 gal. of pure water weighs 8.345 lb.

For approximations, 1 cu. ft. of water is considered equal to 7½ gal., and 1 gal. as weighing 8⅓ lb.

The *British imperial gallon*, both liquid and dry, contains 277.274 cu. in = .16046 cu. ft., and is equivalent to the volume of 10 lb. of pure water at 62° F.

To reduce U. S. to British liquid gallons, divide by 1.2. Conversely, to convert British into U. S. liquid gallons, multiply by 1.2; or, increase the number of gallons ⅕.

MISCELLANEOUS TABLE

12 articles = 1 dozen.
12 dozen = 1 gross.
12 gross = 1 great gross.
2 articles = 1 pair.
20 articles = 1 score.
24 sheets = 1 quire.

20 quires = 1 ream.
1 league = 3 mi.
1 fathom = 6 ft.
1 hand = 4 in.
1 palm = 3 in.
1 span = 9 in.

1 knot (U. S.) = 6,080 ft. = 1.15 mi. (roughly).
1 meter = 3 ft. 3⅜ in. (nearly).

THE METRIC SYSTEM

The *metric system* is based on the meter, which, according to the U. S. Coast and Geodetic Survey Report of 1884, is equal to 39.370432 in. The value commonly used is 39.37 in., and is authorized by the U. S. government. The meter is defined as one ten-millionth the distance from the pole to the equator, measured on a meridian passing near Paris.

There are three principal units—the meter, the liter (pronounced lee-ter), and the gram, the units of length, capacity, and weight, respectively. Multiples of these units are obtained by prefixing to the names of the principal units the Greek words *deca* (10), *hecto* (100), and *kilo* (1,000); the submultiples, or divisions, are obtained by prefixing the Latin words *deci* ($\frac{1}{10}$), *centi* ($\frac{1}{100}$), and *milli* ($\frac{1}{1000}$). These prefixes form the key to the entire system. In the following tables, the abbreviations of the principal units of these submultiples begin with a small letter, while those of the multiples begin with a capital letter; they should always be written as here printed.

MEASURES OF LENGTH

Name		*Meters*		*U.S. In.*		*U.S. Ft.*
Millimeter (mm.)	=	.001	=	.039370	=	.003281
Centimeter (cm.)	=	.010	=	.393704	=	.032809
Decimeter (dm.)	=	.100	=	3.937043	=	.328087
Meter (m.)	=	1.000	=	39.370432	=	3.280869
Decameter (Dm.)	=	10.000			=	32.808690
Hectometer (Hm.)	=	100.000			=	328.086900
Kilometer (Km.)	=	1,000.000	=	.621 mi.	=	3,280.869000
Myriameter (Mm.)	=	10,000.000	=	6.214 mi.	=	32,808.690000

The centimeter, meter, and kilometer are the units in practical use, and may be said to occupy the same position in the metric system as do inches, yards, and miles in the U. S. and English system of measurement.

MEASURES OF AREA

Name	*Sq. M.*	*Sq. In.*	*Sq. Ft.*	*A.*
Sq. millimeter (sq. mm.)	= .0000010	= .001550		
Sq. centimeter (sq. cm.)	= .0001000	= .155003	= .00107641	
Sq. decimeter (sq. dm.)	= .0100000	= 15.5003	= .10764100	
Sq. meter, or centare (sq.m., or ca.)	= 1.000000	= 1,550.03	= 10.764100	= .000247
Sq.decameter, or are (sq. Dm., or A.)	= 100.0000	= 155,003	= 1,076.4101	= .024710
Hectare	= 10,000.00		= 107,641.01	= 2.47110
Sq. kilometer	= .3861099 sq. mi.		= 10,764,101	= 247.110
Sq. myriameter	= 38.61090 sq. mi.			= 24,711.0

MEASURES OF VOLUME

Name	*Cu. M.*	*Cu. In.*	*Cu. Ft.*	*Cu. Yd.*
Cu. centimeter (c.c. or cu.cm.)	= .000001	= .061025		
Cu. decimeter (cu. dm.)	= .001000	= 61.0254		
Centistere	= .010000	= 610.2540	= .35316	
Decistere	= .100000		= 3.53156	
Stere (cu. m.)	= 1.000000		= 35.3156	= 1.308
Decastere	= 10.000000		= 353.156	= 13.080

MEASURES OF CAPACITY

Name	*Liters*	*Liq. Meas.*	*Dry Meas.*
Milliliter (ml. = c.c.)	= .00100	= .008454 gi.	= .001816 pt.
Centiliter (cl.)	= .01000	= .084537 gi.	= .018162 pt.
Deciliter (dl.)	= .10000	= .845370 gi.	= .18162 pt.
Liter (l.)(= cu.dm.)	= 1.0000	= 1.05671 qt. .264179 gal.	= .11351 pk.

Decaliter (Dl.) (= centistere) } = 10.000 = 2.64179 gal. = 1.1351 pk.
Hectoliter (Hl.) (= decistere) } = 100.00 = 26.4179 gal. = 2.83783 bu.
Kiloliter (Kl.) (= cu.m., or stere) } = 1,000.0 = 264.179 gal. = 28.3783 bu.
Myrialiter (Ml.) (= decastere) } = 10,000 = 2641.79 gal. = 283.783 bu.

The milliliter (or cubic centimeter) and the liter are the units most commonly used. A liter of pure water at 4° C., or 39.2° F., weighs 1 Kg.

METRIC WEIGHTS

The gram is the basis of metric weights, and is the weight of a cubic centimeter of distilled water at its maximum density, at sea level, Paris, barometer 29.922 inches.

Name	*Grams*	*Grains*	*Av. Oz.*	*Av. Lb.*
Milligram (mg.)	.001	.01543		
Centigram (cg.)	.010	.15432		
Decigram (dg.)	.100	1.54323		
Gram (g.)	1.000	15.43235	.03527	.0022046
Decagram (Dg.)	10.000		.35274	.0220462
Hectogr'm (Hg)	100.000		3.52739	.2204622
Kilogram (Kg.)	1,000.000		35.27395	2.2046223
Myriagr'm (Mg)	10,000.000			22.0462234
Quintal (Q.)	100,000.000			220.4622341
Tonneau (T.)	1,000,000.000			2,204.6223410

The gram and the kilogram (called *kilo*) are the units in common use.

FACTORS FOR CONVERSION

For approximations, it may be useful to remember the following:

1 cm. = .4 in. (nearly)
1 m. = 40 in. (roughly)
1 Km. = $\frac{5}{8}$ mi. (nearly)
1 l. = 1 liq. qt. (nearly)
1 l. = $\frac{1}{9}$ pk. (nearly)
1 gr. = 15.4 gr.
1 Kg. = $2\frac{1}{5}$ lb.

To convert metric measures into U. S. measures, by use of the preceding tables, find the desired equivalent in U. S. measure of a metric unit of the denomination given, and multiply this equivalent by the metric number. For example, it is desired to find the equivalent in pounds of 19.6 Kg. From the table of weights 1 Kg. = 2.2046 lb.; hence, 19.6 Kg. = 2.2046 × 19.6 = 43.21 lb. In similar manner, 8 l. = .264179 × 8 = 2.113432 U. S. gal.

To convert U. S. measures into metric measures, find how much a metric unit of the desired denomination is equal to in U. S. measure, and divide the given number by this equivalent. For example, it is desired to convert $4\frac{1}{2}$ mi. into kilometers. From the table of lengths, it is found that 1 Km. is .621 mi.; hence, dividing 4.5 by .621, the result is 7.24 Km.

Other useful conversion factors are as follows:

Length.—1 in. = .0254 m.; 1 ft. = .3048 m.; 1 yd. = .9144 m.; 1 mi. = 1,609.34 m. = 1.609 Km.

Area.—1 sq. in. = .000645 sq. m.; 1 sq. ft. = .0929 sq. m.; 1 sq. yd. = .836 sq. m.; 1 A. = 4,047 sq. m.

Capacity.—1 cu. in. = .0164 l.; 1 U. S. bu. = 35.24 l.; 1 U. S. dry qt. = 1.101 l.; 1 U. S. pk. = 8.81 l.; 1 cu. yd. = 765 l.; 1 U. S. liq. qt. = .9463 l.; 1 U. S. gal. = 3.785 l.

Weight.—1 grain = .0648 gram; 1 av. oz. = 28.349 grams; 1 Troy oz. = 31.103 grams; 1 av. lb. = 453.59 grams.

FORMULAS

Formulas are simply short methods of indicating operations otherwise expressed by rules, by using letters and signs in place of words. The letters are usually those of the English alphabet, and the signs are those previously given. Besides showing at a glance the various steps, formulas are much more convenient to memorize than rules and also can be more readily followed. Explanations will be given of some simple formulas, and it will be shown how a formula may be transposed so as to obtain any required term.

To show the similarity between a rule and a formula, let it be required to find the area of footing necessary to sustain a certain load, having given the safe load per square foot.

The rule is: *Divide the total load, in pounds, by the safe load, in pounds per square foot; the quotient is the required area, in square feet.* Not much space can be saved by expressing such a simple rule in a formula, but the operation is more quickly comprehended. Let P = total load, in pounds; S = safe load per square foot; A = required area.

Then the rule is expressed by the formula

$$A=\frac{P}{S}$$

A formula is used by substituting for the letters the quantities known in the problem, and finding the unknown quantity by performing the indicated operations. Sometimes the formula as written does not give the desired quantity directly, but must be rearranged so as to enable it to be found. This is done by simple operations, the aim being to obtain the desired quantity by itself on one side of the equality sign. Thus, in the foregoing formula, suppose it is desired to find the value of P when A and S are given. By multiplying A and $\frac{P}{S}$ by S (such operation being called *clearing of fractions*) there results $A\times S=P$, in which the desired quantity P is by itself and is found to be equal to the product of A and S. The formula is further shortened by omitting the × sign, and writing $A\ S=P$. When two or more letters are thus written, it means that they are to be multiplied together. In a similar manner, S may be obtained by dividing the last found formula through by A; thus, $S=\frac{P}{A}$.

EXAMPLE 1.—The safe bearing power of a soil is 1,500 lb. per sq. ft. What area of footing is required to sustain a load of 30,000 lb.?

SOLUTION.—Here A is wanted, and P and S are given. Hence, $A=\frac{P}{S}=\frac{30{,}000}{1{,}500}=20$ sq. ft.

EXAMPLE 2.—If the total load is 30,000 lb., how much, per square foot, will be carried by a footing 20 sq. ft. in area?

Solution.—Here, A and P are given to find S; or $S=\frac{P}{A}$ $=\frac{30{,}000}{20}=1{,}500$ lb.

The following formula is used to determine the safe total quiescent load that a wooden beam will carry, if uniformly loaded:

$$W=c\frac{bd^2}{l}$$

in which b = breadth of beam, in inches;
d = depth of beam, in inches;
c = a constant, depending on kind of wood, etc.;
l = length of span, in inches;
W = safe total load, uniformly distributed.

If any other quantity than W is wanted it may be found by transposing the formula; thus, if the depth necessary to sustain a certain load is required, the formula is changed in the following manner.

Multiplying through by l, $Wl=bd^2c$. Dividing by bc, $d^2=\frac{Wl}{bc}$. Extracting the square root, $d=\sqrt{\frac{Wl}{bc}}$

Example.—It is desired to carry a distributed load of 10,000 lb. on a dry long-leaf pine beam that is 8 in. wide and has a span of 8 ft. 4 in. How thick must the beam be?

Solution.—The value to be given to c depends on the kind of wood, quality of wood, dryness of wood, method in which beam is placed, kind of load, and degree of safety required. In this problem it will be taken as 1,600. Substituting the values there results,

$$d=\sqrt{\frac{10{,}000\times 100}{8\times 1{,}600}}=8.8 \text{ in. say } 9 \text{ in.}$$

A rule for finding the safe unit stress in a wooden column is as follows:

Rule.—*From 1 subtract one-third of the fourth power of the quotient obtained by dividing the length of the column, in inches, the product of the least width of the column, in inches, and a constant which depends on the species and quality of the wood.*

Multiply the remainder by the safe unit stress for a short block of the wood.

This rule is rendered much more intelligible by the formula

$$f=f_1\left[1-\frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$$

in which f = allowable unit stress for column, in pounds per square inch;
f_1 = allowable unit stress for short block;
l = length of column, in inches;
d = least width of column, in inches;
K = constant.

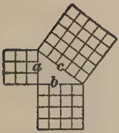
Example.—The allowable unit stress f_1 for a short block of a certain grade of southern pine is 1,285 lb. per sq. in., and the corresponding value of K is 22.6. What is the allowable unit stress for a 10″×10″ column 16 ft. long?

Solution.—In the formula, $f_1=1{,}285$, $l=16\times12=192$ in., $K=22.6$, and $d=10$ in. Hence,

$$f=1{,}285\left[1-\frac{1}{3}\left(\frac{192}{22.6\times10}\right)^4\right]$$
$$=1{,}285\times(1-\tfrac{1}{3}\times.522)$$
$$=1{,}285\times.826=1.060 \text{ lb. per sq. in.}$$

MENSURATION

TRIANGLE



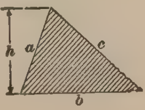
For a right triangle

Hypotenuse $c=\sqrt{a^2+b^2}$

Side $a=\sqrt{c^2-b^2}$

Side $b=\sqrt{c^2-a^2}$

Area $=\frac{1}{2}ab$



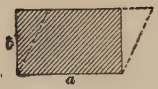
For an oblique triangle. If altitude or height h and base b are known:

Area $=\frac{1}{2}bh$

If the three sides are known:

let $s=\frac{1}{2}(a+b+c)$

Area $=\sqrt{s(s-a)(s-b)(s-c)}$

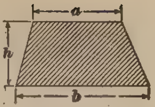


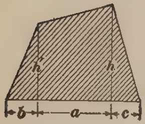
PARALLELOGRAM

Area $= ab$

TRAPEZOID

Area $= \frac{1}{2} h(a+b)$





TRAPEZIUM

Divide into two triangles and a trapezoid.

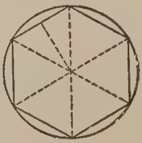
Area $= \frac{1}{2} bh' + \frac{1}{2} a(h'+h) + \frac{1}{2} ch$;

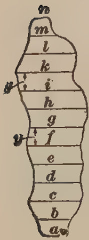
or, area $= \frac{1}{2}[bh' + ch + a(h'+h)]$

REGULAR POLYGONS

Divide the polygon into equal triangles and find the sum of the partial areas. Otherwise, square the length of one side and multiply by proper number from the following table:

Name	*No. Sides*	*Multiplier*
Triangle	3	.433
Square	4	1.000
Pentagon	5	1.720
Hexagon	6	2.598
Heptagon	7	3.634
Octagon	8	4.828
Nonagon	9	6.182
Decagon	10	7.694





IRREGULAR AREAS

Divide the area into trapezoids, triangles, parts of circles, etc., and find the sum of the partial areas. If the figure is very irregular, the approximate area may be found as follows: Divide the figure into trapezoids by equidistant parallel lines b, c, d, etc. The lengths of these lines being measured, then, calling a the first and n the last length, and y the width of strips,

$$\text{Area} = y\left(\frac{a+n}{2} + b + c + \text{etc.} + m\right)$$

CIRCLE

A = area;

$\pi (pi) = 3.1416$;

$\frac{\pi}{4} = .7854$;

p = perimeter or circumference;

$p = \pi d = 3.1416\ d$;

$p = 3\frac{1}{7}\ d$ (approximately);

$p = 2\ \pi r = 6.2832\ r$;

$d = \frac{p}{\pi} = \frac{p}{3.1416}$

$d = \frac{7}{22} p$ (approximately);

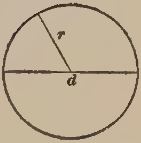
$d = 1.128 \sqrt{A}$;

$r = \frac{p}{2\ \pi} = \frac{p}{6.2832}$;

$r = .5642 \sqrt{A}$;

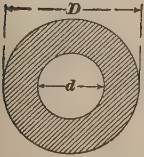
$A = \frac{\pi d^2}{4} = .7854\ d^2$;

$A = \pi r^2 = 3.1416\ r^2$.



Side of square of area equal to circle $= .8862\ d$.

Diameter of circle of area equal to a given square $= 1.128 \times$ side.



RING

Area $= .7854 (D^2 - d^2)$

SECTOR

If radius r and rise h are known,

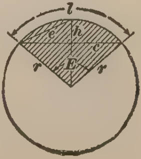
chord $c = 2 \sqrt{2\ hr - h^2}$.

If chord c and rise h are known,

radius $r = \frac{c^2 + 4\ h^2}{8\ h}$

Approximately, $r = \frac{c^2}{8\ h}$

Subchord $e = \frac{1}{2} \sqrt{c^2 + 4\ h^2}$



If h is not more than .4 c, length of arc $l = \frac{8\,e - c}{3}$, nearly

If l and r are known,

$$\text{Angle } E^* = 57.296\frac{l}{r}, = 57.3\,\frac{l}{r}, \text{ nearly}$$

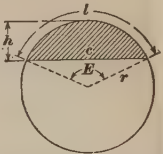
$$\text{Area} = \tfrac{1}{2}\,lr$$

If r and angle E^* are known,

$$\text{length } l = \frac{Er}{57.296} = \frac{Er}{57.3}, \text{ (nearly)} = .0175\,Er.$$

$$\text{Area} = .0087\ r^2E$$

SEGMENT



Area of segment = area of sector − area of triangle.

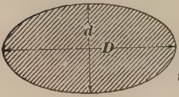
Height of triangle $= r - h$

If l, r, c, and h are known,

$$\text{Area} = \tfrac{1}{2}\,lr - \tfrac{1}{2}\,c(r-h)$$

If c, h, r, and E are known, find l as shown under *Sector;* the area may then be found by the preceding formula.

ELLIPSE



$$p = \pi\left(\frac{D+d}{2}\right)\frac{64 - 3\,q^4}{64 - 16\,q^2}\dagger$$

In which p = the perimeter, D and d are the two diameters, and

$$q = \frac{D-d}{D+d}$$

$$\text{Area} = .7854\ Dd$$

---

*If the angle E contains minutes and seconds, these must be expressed in decimals of a degree. Divide the minutes by 60, and the seconds (if any) by 3,600, and add the sum of the decimals to the degrees; thus, 30° 45′ 36″ = $30° + \frac{45}{60} + \frac{36}{3600}$ = 30.76°. If E is given in degrees and decimals, it may be reduced to minutes and seconds thus: .76° = .76 × 60 = 45.6′; .6 × 60 = 36″; hence, 30.76° = 30° 45′ 36″.

†The perimeter of an ellipse cannot be exactly determined, and this formula is merely an approximation giving very close results.

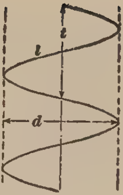
HELIX

d = diameter of helix;
l = length of one turn of helix;
t = pitch, or rise in one turn;
n = number of turns;
$\pi^2 = 9.8696$;

$$l = \sqrt{\pi^2 d^2 + t^2}$$

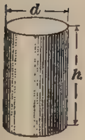
$$t = \sqrt{l^2 - \pi^2 d^2}$$

$$\text{Total length} = nl = n\sqrt{\pi^2 d^2 + t^2}$$



MEANING OF SYMBOLS

C = convex surface;
S = whole surface;
$= C +$ area of end or ends;
A = area larger base or end;
a = area smaller base or end;
P = perimeter of larger base;
p = perimeter of smaller base;
D = larger diameter;
d = smaller diameter;
V = volume of solid.
In a cylinder or prism,
$A = a$, $P = p$, and $D = d$

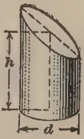


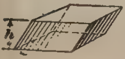
CYLINDER

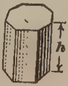
$C = Ph = 3.1416\ dh$
$S = 3.1416\ dh + 1.5708\ d^2$
$V = Ah = .7854\ d^2h$

FRUSTUM OF CYLINDER

$h = \frac{1}{2}$ sum of greatest and least heights
$C = Ph = 3.1416\ dh$
$S = 3.1416\ dh + .7854\ d^2 +$ area of elliptic top
$V = Ah = .7854\ d^2h$







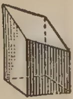
PRISM OR PARALLELOPIPED

$C = Ph$
$S = Ph + 2A$
$V = Ah$

For prisms with regular polygons as bases, P = length of one side × number of sides.

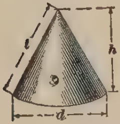
To obtain area of base, if it is a polygon, divide it into triangles, and find sum of partial areas.

FRUSTUM OF PRISM



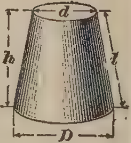
If a section perpendicular to the edges, called the right section, is a triangle, square, parallelogram, or regular polygon,

$$V=\frac{\text{sum of lengths of edges}}{\text{number of edges}}\times\text{area of right section}$$



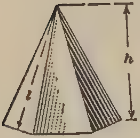
CONE

$$C=\tfrac{1}{2}\,Pl=1.5708\,dl$$
$$S=1.5708\,dl+.7854\,d^2$$
$$V=\frac{Ah}{3}=.2618\,d^2h$$



FRUSTUM OF CONE

$$C=\tfrac{1}{2}\,l(P+p)=1.5708\,l(D+d)$$
$$S=1.5708\,l(D+d)+.7854(D^2+d^2)$$
$$V=.2618\,h(D^2+Dd+d^2)$$



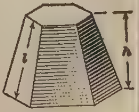
PYRAMID

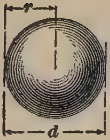
$$C=\tfrac{1}{2}\,Pl$$
$$S=\tfrac{1}{2}\,Pl+A$$
$$V=\frac{Ah}{3}$$

To obtain area of base, divide it into triangles, and find sum of their areas.

FRUSTUM OF PYRAMID

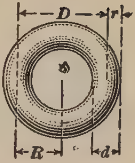
$$C=\tfrac{1}{2}\,l(P+p)$$
$$S=\tfrac{1}{2}\,l(P+p)+A+a$$
$$V=\tfrac{1}{3}\,h\left(A+a+\sqrt{Aa}\right)$$





SPHERE

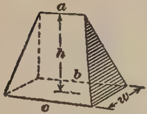
$$S=3.1416\,d^2=12.5664\,r^2$$
$$V=.5236\,d^3=4.1888\,r^3$$



CIRCULAR RING

D = mean diameter;
R = mean radius.

$$S=4\,\pi^2Rr=9.8696\,Dd$$
$$V=2\,\pi^2Rr^2=2.4674\,Dd^2$$

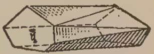


WEDGE

$$V=\tfrac{1}{6}\,wh(a+b+c)$$

PRISMOID

A *prismoid* is a solid having two parallel plane ends, the edges of which are connected by plane triangular or quadrilateral surfaces.



A = area one end;
a = area of other end;
m = area of section midway between ends;
l = perpendicular distance between ends;

$$V=\tfrac{1}{6}\,l(A+a+4m)$$

The area m is not in general a mean between the areas of the two ends, but its sides are means between the corresponding lengths of the ends.

$$\text{Approximately, } V=\frac{A+a}{2}\,l$$

ROOF MENSURATION

Although the ordinary principles of mensuration are all that are necessary in calculating any roof area, the modern house, with its numerous gables and irregular surfaces, introduces complications that render some further explanation of roof measurement desirable. The most common error made in figuring roofs, which should be carefully avoided, is that of using the apparent length of slopes, as shown by the plan or side elevation, instead of the true length, obtained from the end elevations.

The area of a plain gable roof, as shown in end and side elevations in Fig. 1 (*a*), is found by multiplying the length *gj* by the slope length *bd*, and further multiplying by 2, for both sides. The area of each gable is found by multiplying the width of the gable *ad* by the altitude *cb* and dividing by 2.

In (*b*) is shown the plan and the elevation of a hip roof, having a deck *z*. The pitch of the roof being the same on each side, the line *cd* shows the true length of the common rafter *lm*; *ce* is the height of the deck above *ad*. In (*c*) is shown the method of determining the true lengths of the hips, and the true size of one side of the roof. Let *abcd* represent the same lines as the corresponding ones in (*b*). To the line *ad*, through *b* and *c*, draw perpendiculars, as *gh* and *ef*; lay off from *g* and *e* on these lines the length of the common rafter *ab*, in (*b*), and draw the lines *ah* and *df*; then the figure *ahfd* will show the true shape and size of that side of the roof shown in the elevation in (*b*). The triangle *def* equals in area the triangle *agh* or a similar triangle *aih*. Hence, the portion of the roof *ahfd* is equal in area to the rectangle *aife*, whose length is one-half the sum of the eaves and deck lengths, and whose breadth is the length of a common rafter.

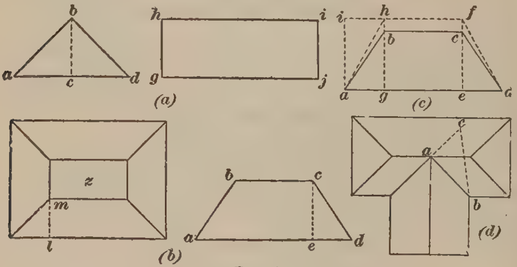


FIG. 1

A method of obtaining the lengths of valleys—and which is also applicable to hip rafters—is shown in (*d*), which is the plan of a hip-and-gable roof. To ascertain the length of the valley rafter *ab*, draw the line *ac* perpendicular to the line *ab* and equal in length to the altitude of the gable; then draw the line *cb*, which will be the length required.

As an example of roof mensuration, the number of square feet of surface on the roof shown in Fig. 2 will be calculated. The area of the triangular portion *acb* is equal to one-half the base, *ab*, multiplied by the slope length of *cd*. The latter

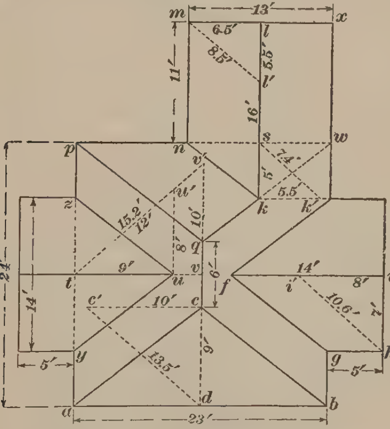


FIG. 2

is found by making *cc′*, perpendicular to *dc*, equal to the height of the ridge (10 ft.) above *ab*, and drawing *c′d*, which is the required slope length. Using dimensions, the area of *acb* is $\frac{23\times 13.5}{2}=155.3$ sq. ft.

The area of the trapezoid *gfih* is one-half the sum of *fi* and *gh*, multiplied by the true length of *hi*, which, by laying off *ii′*, 8 ft. along *fi*, and drawing *i′h*, is found to be 10.6 ft.

Then $gfih=\frac{14+5}{2}\times 10.6=100.7$ sq. ft.; or, for the two slopes of the gable, the area is 201.4 sq. ft. As the opposite gable is the same size, the area of the two is $201.4\times 2=402.8$ sq. ft.

The area of *qpnk* is equal to the area *qpw*, minus the area *knw*, which is covered by the intersecting gable roof. The area *qpw* is equal to the area *acb*, or 155.3 sq. ft. The area of *knw* is equal to one-half the product of *nw* and the slope of *sk* (which, by laying off *kk′* equal to the height of the gable, 5.5 ft., and drawing *sk′*, is found to be 7.4 ft.). Then area $knw=\frac{13\times 7.4}{2}=48.1$ sq. ft., which, deducted from 155.3 sq. ft., shows the area of *qpnk* to be 107.2 sq. ft.

The area of *apqc* is $\frac{ap+qc}{2}$ multiplied by the true slope length of *tv*, which is *tv′*, measuring 15.2 ft. Substituting dimensions, the area is found to be $\frac{6+24}{2}\times 15.2=228$ sq. ft. From this deduct the area of *yzu*, which is the portion covered by the intersecting gable roof. The true length of *tu* along the slope is *tu′*, which measures 12 ft.; hence, the area of *yzu* is $\frac{14\times 12}{2}=84$ sq. ft. The net area of *apqc* is, therefore, $228-84=144$ sq. ft.; *bcqw* being equal to *apqc*, its area is the same, making the area of both sides 288 sq. ft.

The area of *knml* is $\frac{mn+lk}{2}\times ml'$, the slope length of *ml*. Substituting dimensions, the area is $\frac{11+16}{2}\times 8.5=114.8$ sq. ft. As *klxw* is equal to *knml*, the area of both is 229.6 sq. ft. Adding the partial areas thus obtained, the sum is $155.3+402.8+107.2+288+229.6=1{,}182.9$ sq. ft., or 11.9 squares.

CIRCUMFERENCES AND AREAS OF CIRCLES

The following table gives the diameter, the circumference, or the area when either of the other values is known. Thus, the diameter of a circle having an area of 7,200 sq. in. is, approximately, 95¾ in. and its circumference, nearly 301 in.

CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1-64 TO 100

Diam.	Circum.	Area	Diam.	Circum.	Area
1/64	.0491	.0002	4	12.5664	12.5664
1/32	.0982	.0008	4 1/8	12.9591	13.3641
1/16	.1963	.0031	4 1/4	13.3518	14.1863
1/8	.3927	.0123	4 3/8	13.7445	15.0330
3/16	.5890	.0276	4 1/2	14.1372	15.9043
1/4	.7854	.0491	4 5/8	14.5299	16.8002
5/16	.9817	.0767	4 3/4	14.9226	17.7206
3/8	1.1781	.1104	4 7/8	15.3153	18.6555
7/16	1.3744	.1503	5	15.7080	19.6350
1/2	1.5708	.1963	5 1/8	16.1007	20.6290
9/16	1.7671	.2485	5 1/4	16.4934	21.6476
5/8	1.9635	.3068	5 3/8	16.8861	22.6907
11/16	2.1598	.3712	5 1/2	17.2788	23.7583
3/4	2.3562	.4418	5 5/8	17.6715	24.8505
13/16	2.5525	.5185	5 3/4	18.0642	25.9673
7/8	2.7489	.6013	5 7/8	18.4569	27.1086
15/16	2.9452	.6903	6	18.8496	28.2744
1	3.1416	.7854	6 1/8	19.2423	29.4648
1 1/8	3.5343	.9940	6 1/4	19.6350	30.6797
1 1/4	3.9270	1.2272	6 3/8	20.0277	31.9191
1 3/8	4.3197	1.4849	6 1/2	20.4204	33.1831
1 1/2	4.7124	1.7671	6 5/8	20.8131	34.4717
1 5/8	5.1051	2.0739	6 3/4	21.2058	35.7848
1 3/4	5.4978	2.4053	6 7/8	21.5985	37.1224
1 7/8	5.8905	2.7612	7	21.9912	38.4846
2	6.2832	3.1416	7 1/8	22.3839	39.8713
2 1/8	6.6759	3.5466	7 1/4	22.7766	41.2826
2 1/4	7.0686	3.9761	7 3/8	23.1693	42.7184
2 3/8	7.4613	4.4301	7 1/2	23.5620	44.1787
2 1/2	7.8540	4.9087	7 5/8	23.9547	45.6636
2 5/8	8.2467	5.4119	7 3/4	24.3474	47.1731
2 3/4	8.6394	5.9396	7 7/8	24.7401	48.7071
2 7/8	9.0321	6.4918	8	25.1328	50.2656
3	9.4248	7.0686	8 1/8	25.5255	51.8487
3 1/8	9.8175	7.6699	8 1/4	25.9182	53.4563
3 1/4	10.2102	8.2958	8 3/8	26.3109	55.0884
3 3/8	10.6029	8.9462	8 1/2	26.7036	56.7451
3 1/2	10.9956	9.6211	8 5/8	27.0963	58.4264
3 5/8	11.3883	10.3206	8 3/4	27.4890	60.1322
3 3/4	11.7810	11.0447	8 7/8	27.8817	61.8625
3 7/8	12.1737	11.7933	9	28.2744	63.6174

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
9⅛	28.6671	65.3968	19½	61.2612	298.648
9¼	29.0598	67.2008	19¾	62.0466	306.355
9⅜	29.4525	69.0293	20	62.8320	314.160
9½	29.8452	70.8823	20¼	63.6174	322.063
9⅝	30.2379	72.7599	20½	64.4028	330.064
9¾	30.6306	74.6621	20¾	65.1882	338.164
9⅞	31.0233	76.589	21	65.9736	346.361
10	31.4160	78.540	21¼	66.7590	354.657
10¼	32.2014	82.516	21½	67.5444	363.051
10½	32.9868	86.590	21¾	68.3298	371.543
10¾	33.7722	90.763	22	69.1152	380.134
11	34.5576	95.033	22¼	69.9006	388.822
11¼	35.3430	99.402	22½	70.6860	397.609
11½	36.1284	103.869	22¾	71.4714	406.494
11¾	36.9138	108.434	23	72.2568	415.477
12	37.6992	113.098	23¼	73.0422	424.558
12¼	38.4846	117.859	23½	73.8276	433.737
12½	39.2700	122.719	23¾	74.6130	443.015
12¾	40.0554	127.677	24	75.3984	452.390
13	40.8408	132.733	24¼	76.1838	461.864
13¼	41.6262	137.887	24½	76.9692	471.436
13½	42.4116	143.139	24¾	77.7546	481.107
13¾	43.1970	148.490	25	78.5400	490.875
14	43.9824	153.938	25¼	79.3254	500.742
14¼	44.7678	159.485	25½	80.1108	510.706
14½	45.5532	165.130	25¾	80.8962	520.769
14¾	46.3386	170.874	26	81.6816	530.930
15	47.1240	176.715	26¼	82.4670	541.190
15¼	47.9094	182.655	26½	83.2524	551.547
15½	48.6948	188.692	26¾	84.0378	562.003
15¾	49.4802	194.828	27	84.8232	572.557
16	50.2656	201.062	27¼	85.6086	583.209
16¼	51.0510	207.395	27½	86.3940	593.959
16½	51.8364	213.825	27¾	87.1794	604.807
16¾	52.6218	220.354	28	87.9648	615.754
17	53.4072	226.981	28¼	88.7502	626.798
17¼	54.1926	233.706	28½	89.5356	637.941
17½	54.9780	240.529	28¾	90.3210	649.182
17¾	55.7634	247.450	29	91.1064	660.521
18	56.5488	254.470	29¼	91.8918	671.959
18¼	57.3342	261.587	29½	92.6772	683.494
18½	58.1196	268.803	29¾	93.4626	695.128
18¾	58.9050	276.117	30	94.2480	706.860
19	59.6904	283.529	30¼	95.0334	718.690
19¼	60.4758	291.040	30½	95.8188	730.618

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
30¾	96.6042	742.645	42	131.947	1,385.45
31	97.3896	754.769	42¼	132.733	1,401.99
31¼	98.1750	766.992	42½	133.518	1,418.63
31½	98.9604	779.313	42¾	134.303	1,435.37
31¾	99.7458	791.732	43	135.089	1,452.20
32	100.5312	804.250	43¼	135.874	1,469.14
32¼	101.3166	816.865	43½	136.660	1,486.17
32½	102.1020	829.579	43¾	137.445	1,503.30
32¾	102.8874	842.391	44	138.230	1,520.53
33	103.673	855.301	44¼	139.016	1,537.86
33¼	104.458	868.309	44½	139.801	1,555.29
33½	105.244	881.415	44¾	140.587	1,572.81
33¾	106.029	894.620	45	141.372	1,590.43
34	106.814	907.922	45¼	142.157	1,608.16
34¼	107.600	921.323	45½	142.943	1,625.97
34½	108.385	934.822	45¾	143.728	1,643.89
34¾	109.171	948.420	46	144.514	1,661.91
35	109.956	962.115	46¼	145.299	1,680.02
35¼	110.741	975.909	46½	146.084	1,698.23
35½	111.527	989.800	46¾	146.870	1,716.54
35¾	112.312	1,003.790	47	147.655	1,734.95
36	113.098	1,017.878	47¼	148.441	1,753.45
36¼	113.883	1,032.065	47½	149.226	1,772.06
36½	114.668	1,046.349	47¾	150.011	1,790.76
36¾	115.454	1,060.732	48	150.797	1,809.56
37	116.239	1,075.213	48¼	151.582	1,828.46
37¼	117.025	1,089.792	48½	152.368	1,847.46
37½	117.810	1,104.469	48¾	153.153	1,866.55
37¾	118.595	1,119.244	49	153.938	1,885.75
38	119.381	1,134.118	49¼	154.724	1,905.04
38¼	120.166	1,149.089	49½	155.509	1,924.43
38½	120.952	1,164.159	49¾	156.295	1,943.91
38¾	121.737	1,179.327	50	157.080	1,963.50
39	122.522	1,194.593	50½	158.651	2,002.97
39¼	123.308	1,209.958	51	160.222	2,042.83
39½	124.093	1,225.420	51½	161.792	2,083.08
39¾	124.879	1,240.981	52	163.363	2,123.72
40	125.664	1,256.640	52½	164.934	2,164.76
40¼	126.449	1,272.400	53	166.505	2,206.19
40½	127.235	1,288.250	53½	168.076	2,248.01
40¾	128.020	1,304.210	54	169.646	2,290.23
41	128.806	1,320.260	54½	171.217	2,332.83
41¼	129.591	1,336.410	55	172.788	2,375.83
41½	130.376	1,352.660	55½	174.359	2,419.23
41¾	131.162	1,369.000	56	175.930	2,463.01

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
56½	177.500	2,507.19	78½	246.616	4,839.83
57	179.071	2,551.76	79	248.186	4,901.68
57½	180.642	2,596.73	79½	249.757	4,963.92
58	182.213	2,642.09	80	251.328	5,026.56
58½	183.784	2,687.84	80½	252.899	5,089.59
59	185.354	2,733.98	81	254.470	5,153.01
59½	186.925	2,780.51	81½	256.040	5,216.82
60	188.496	2,827.44	82	257.611	5,281.03
60½	190.067	2,874.76	82½	259.182	5,345.63
61	191.638	2,922.47	83	260.753	5,410.62
61½	193.208	2,970.58	83½	262.324	5,476.01
62	194.779	3,019.08	84	263.894	5,541.78
62½	196.350	3,067.97	84½	265.465	5,607.95
63	197.921	3,117.25	85	267.036	5,674.51
63½	199.492	3,166.93	85½	268.607	5,741.47
64	201.062	3,217.00	86	270.178	5,808.82
64½	202.633	3,267.46	86½	271.748	5,876.56
65	204.204	3,318.31	87	273.319	5,944.69
65½	205.775	3,369.56	87½	274.890	6,013.22
66	207.346	3,421.20	88	276.461	6,082.14
66½	208.916	3,473.24	88½	278.032	6,151.45
67	210.487	3,525.66	89	279.602	6,221.15
67½	212.058	3,578.48	89½	281.173	6,291.25
68	213.629	3,631.69	90	282.744	6,361.74
68½	215.200	3,685.29	90½	284.315	6,432.62
69	216.770	3,739.29	91	285.886	6,503.90
69½	218.341	3,793.68	91½	287.456	6,575.56
70	219.912	3,848.46	92	289.027	6,647.63
70½	221.483	3,903.63	92½	290.598	6,720.08
71	223.054	3,959.20	93	292.169	6,792.92
71½	224.624	4,015.16	93½	293.740	6,866.16
72	226.195	4,071.51	94	295.310	6,939.79
72½	227.766	4,128.26	94½	296.881	7,013.82
73	229.337	4,185.40	95	298.452	7,088.24
73½	230.908	4,242.93	95½	300.023	7,163.04
74	232.478	4,300.85	96	301.594	7,238.25
74½	234.049	4,359.17	96½	303.164	7,313.84
75	235.620	4,417.87	97	304.735	7,389.83
75½	237.191	4,476.98	97½	306.306	7,466.21
76	238.762	4,536.47	98	307.877	7,542.98
76½	240.332	4,596.36	98½	309.448	7,620.15
77	241.903	4,656.64	99	311.018	7,697.71
77½	243.474	4,717.31	99½	312.589	7,775.66
78	245.045	4,778.37	100	314.160	7,854.00

GEOMETRICAL DRAWING

PROBLEMS

To Erect a Perpendicular to the Line *bc* **at the Point** *a*.—With *a*, Fig. 1, as a center, and any radius, as *ab*, strike arcs cutting the line at *b* and *c*. From *b* and *c* as centers, and any radius greater than *ba*, strike arcs intersecting at *d*. Draw *da*, which will be perpendicular to *bc* at *a*.

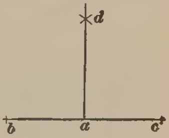


FIG. 1

To Draw a Line Parallel to *ab*.—At any points *a*, Fig. 2, and *b*, with a radius equal to the required distance between the lines, draw arcs at *c* and *d*. The line *cd*, tangent to the arcs, will be the required parallel.

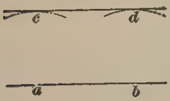


FIG. 2

To Bisect the Angle *bac*.—With *a*, Fig. 3, as a center, strike an arc cutting the sides of the angle in *b* and *c*. With *b* and *c* as centers, and any radius, strike arcs intersecting, as at *d*. Draw *da*, the bisector.

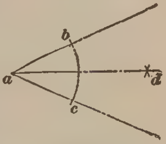


FIG. 3

To Erect a Perpendicular at the End of a Line.—Take a center anywhere above the line, as at *b*, Fig. 4. Strike an arc passing through *a* and cutting the given line at *c*. Draw a line through *c* and *b*, cutting the arc at *d*. Draw the line *ad*, which will be the required perpendicular.

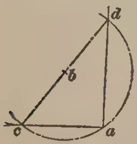


FIG 4

To Divide a Line Into Any Number of Equal Parts.—Let it be required to divide the line *ab*, Fig. 5, into five equal parts. Draw any line *ad*, and point off five equal divisions, as shown. From *5* draw a line to *b* and draw *4-4'*, *3-3'*, etc. parallel to *5b*.

To Divide a Space Between Two Parallel Lines or Surfaces.—An example of this problem is the spacing of risers in a stairway. Draw *ab* and *ce*, Fig. 5, the given distance apart. Then move a scale along them, until as many spaces are included along *ad* as there are number of divisions required. Mark the points *1*, *2*, *3*, etc., and draw lines through them parallel to *ab* and *ce*.

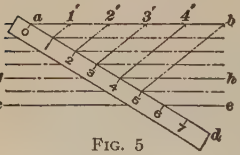


FIG. 5

Magnitude of Angles.—The magnitude of an angle depends not on the length of its sides, but on the number of degrees contained in the arc of a circle drawn with the vertex as a center.

The circle is divided into 360 equal parts, called *degrees*. To divide a quadrant as shown in the figure, first divide it into three parts by the arcs at *e* and *d*, Fig. 6, chords *cd* and *ae* being equal to the radius. Then subdivide with dividers.

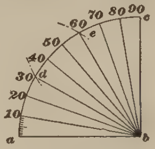


FIG. 6

An *inscribed angle* has its vertex (as *c* or *d*, Fig. 7), in the circumference of a circle. Any angle inscribed in a semicircle is a right angle, as *acb*, or *adb*.

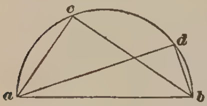


FIG. 7

To Draw a Circle Through Three Points Not in a Straight Line as *a*, *b*, and *c*.—Bisect *ab*, Fig. 8, and also *bc*. The two bisectors will intersect in a point *d*, which will be the center of the required circle.

To Find the Center of a Circular Arc as *a*, *b*, *c*.—Take a point, as *b*, Fig. 8, on the curve, and draw any two chords, *ba* and *bc*. Bisect these lines by perpendiculars; the intersection *d* of these lines will be the required center.

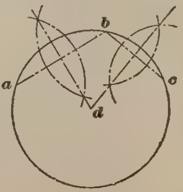


FIG. 8

To Find a Straight Line Nearly Equal to a Semi-Circumference as *a b c*.—On the diameter construct the equilateral triangle *each*, Fig. 9. Through the ends *a* and *c* draw *he* and *hf*; then *ef*, which is tangent to the semi-circumference and parallel to the diameter, is the length of the semi-circumference. Draw any line, as *hkl*; then *lf* is almost exactly the length of arc *kc*, and *bl* that of arc *bk*.

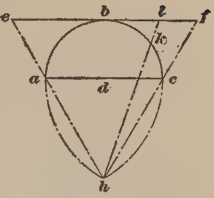


FIG. 9

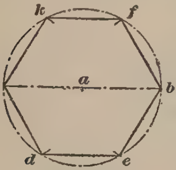


FIG. 10

To Construct a Hexagon From a Given Side.—Describe a circle with a radius *ab* equal to the given side. Draw a diameter as *cb*, Fig. 10. From *c* and *b* as centers, and a radius equal to the given side, draw arcs cutting the circle at *k*, *d*, *f*, and *e*. Connect *c*, *k*, *f*, *b*, *e*, and *d*.

To Inscribe an Octagon in a Square.—Draw the diagonals *ac* and *bd*, Fig. 11. With *a* as a center, and *ae* as a radius, strike an arc cutting the sides of the square at *f* and *h*. Repeat the operation at *b*, *c*, and *d*, and draw lines connecting the eight points thus found to form the figure required.

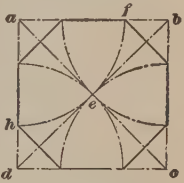


FIG. 11

To Draw Any Regular Polygon in a Circle.—Divide 360° by the number of sides; the quotient will be the angle *aob*, Fig. 12. Lay off this angle at the center with a protractor, and draw its chord, a side of the required polygon. Step this side around on the circumference, and connect the points found.

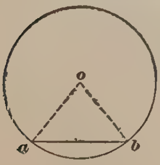


FIG. 12

To Draw a Segment of a Circle, Having Given the Chord *ab* **and Height**

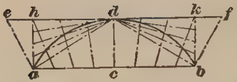


FIG. 13

cd.—Draw *ef*, through *d*, parallel to *ab*; also, *ad* and *db*. Draw *ae* and *bf* perpendicular to *ad* and *db*; also *ah* and *bk* perpendicular to *ab*. Divide *ed*, *df*, *ac*, *cb*, *ah*, and *bk* into the same number of equal parts. Draw lines connecting the points as shown, and trace the curve through the intersections.

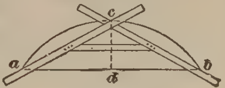


FIG. 14

To Draw a Segment of a Circle by Means of a Fixed Triangle. Let *ab* Fig. 14, be the required chord, and *dc* the rise. Drive nails at *a* and *b*. Make a triangle, as shown, of thin strips, so that the vertex comes at *c*, and stiffen it with the crossbrace. Now, by moving the triangle, always keeping the sides touching the nails at *a* and *b*, the arc may be traced by a pencil held at *c*.

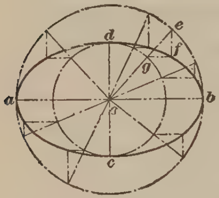


FIG. 15

To Draw an Ellipse, Having Given the Axes.—Draw concentric circles whose diameters are equal to the axes *ab* and *cd*, Fig. 15. From *o* draw any radius as *oe*. From *g*, where *oe* cuts the inner circle, draw *gf* parallel to the major axis *ab*. From *e*, draw *ef* parallel to the minor axis *dc*. The intersection *f* gives a point on the ellipse; other points are similarly found.

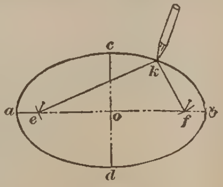


FIG. 16

To Draw an Ellipse With a String, Having Given the Axes ***ab*** **and** ***cd*.**—With *c*, Fig. 16, as a center, and a radius equal to *ob*, strike arcs cutting the major axis at *e* and *f*, the foci of the ellipse. Stick pins at *e* and *f*, and attach a string as shown, the length of the string being equal to the length of the major axis. Keep the string stretched with a pencil point, and sweep around the ellipse.

To Draw a Parabola.—Having given the coordinates *ab* and *bc*, Fig. 17, to draw a parabola, complete the rectangle *abcd*. Divide *bc* and *cd* into the same number of equal parts. From *1′*, *2′*, *3′*, etc., draw lines through *a*. Through *1*, *2*, *3*, etc., draw lines parallel to *ab*. The intersections of *1′a* and *1–1″*, of *2′a* and *2–2″*, etc. are points on the required parabola.

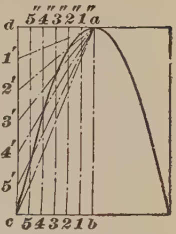


FIG. 17

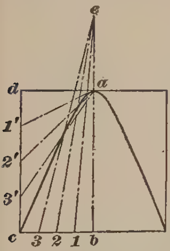
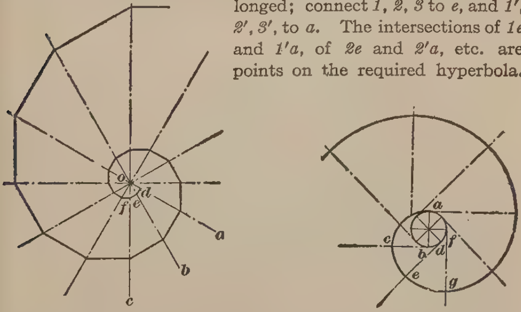


FIG. 18

To Draw a Hyperbola.—Having given the coordinates *ab* and *bc*, Fig. 18, to draw the curve, complete the rectangle *abcd*, and divide *bc* and *cd* into the same number of equal parts. Select any point *e* on the line *ba* prolonged; connect *1*, *2*, *3* to *e*, and *1′*, *2′*, *3′*, to *a*. The intersections of *1e* and *1′a*, of *2e* and *2′a*, etc. are points on the required hyperbola.



(*a*) FIG. 19 (*b*)

The farther *e* is taken from *a*, the more nearly will the hyperbola approach a parabola in form.

To Draw a Spiral.—*First Method.*—From a point, as *o*, Fig. 19 (*a*), draw radiating lines, *oa*, *ob*, *oc*, etc., making equal angles with each other. At any point, as *d*, on *oa*, start the spiral by drawing *de* perpendicular to *oa*; from *e* where *de* intersects *ob*, draw *ef* perpendicular to *ob*; etc. By making the angle between the lines smaller, the spiral may be made to make more turns and the broken line will approach more nearly to a curve.

Second Method.—Draw a small circle, as *bfa*, Fig. 19 (*b*). Divide the circumference into any number of equal parts, eight or more. Draw tangents at the points of division, as *bc*, *de*, etc. With *b* as a center, and *ba* as a radius, strike the arc *ac*. With *d* as a center, and *dc* as a radius, strike the arc *ce*, etc. This method is a very close approximation, though not mathematically correct.

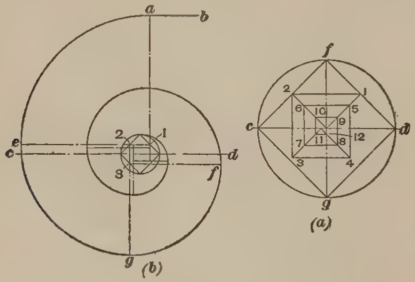


FIG. 20

The Roman Ionic Volute.—For the *eye*, draw the small circle, taking one-fourth the distance between *ab* and *cd*, in Fig. 20 (*b*), as its diameter. In (*a*) is shown the eye enlarged. Mark points *1* and *2*, at the middle of *fd* and *fc*. Divide the line from *2* to the center of the eye into three parts by points *6* and *10*. At a distance below *cd* equal to 2½ times the space between *2–1* and *6–5*, draw *3–4*. Draw the line from *1* to the center of the eye, also *10–9*, *2–3*, and *5–4*. Draw 45° lines

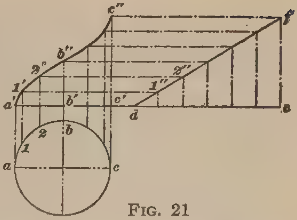


FIG. 21

from *3* and *4*; draw *6–7*, *10–11*, *9–8*, *11–12*, and *7–8*. Use the points thus found as centers, *1* being the center for arc *ae*; *2* for arc *eg*; *3* for arc *gf*; etc.

To Draw a Helix.—A *helix* is the curve assumed by a straight line, as *df*, Fig. 21, drawn on a plane, when the plane is wrapped around a cylindrical surface. To draw a helix, having given the plan of the cylinder *abc* and the rise *c′c″*, divide the arc *abc* into any number of equal parts, as at *1*, *2*, *b*, etc. Divide the line *c′c″* into the same number of equal parts. Draw verticals through the divisions of the arc *abc*, and horizontals through the divisions of *c′c″*, intersecting in points *1′*, *2′*, *b″*, etc. Other points may be similarly found and the curve drawn.

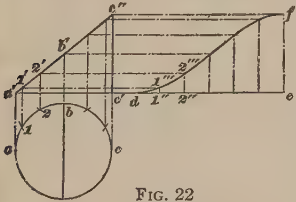


FIG. 22

To Develop the Surface of a Cylinder Cut by a Plane Oblique to the Axis.—Let *abc*, Fig. 22, be the plan of the cylinder, and *a′c″* the inclination of the cutting plane. Divide the arc *abc* into any number of equal parts, as at *1*, *2*, *b*, etc. Draw *de* equal to the semi-circumference, and mark the same divisions as on the arc, as *d–1″*, *1″–2″*, etc. After locating the points *1′*, *2*, etc. by means of verticals through the divisions on the arc, draw horizontal lines through these points, intersecting verticals drawn through *1″*, *2″*, etc., as shown. Trace a curve through the points *d*, *1‴*, *2‴*, etc., and the figure *dfe* will be the development of the half cylinder *abc*.

LAYING OUT ANGLES

By 2-Ft. Rule.—To lay off any angle given in the following table, by means of a 2-ft. rule, open the rule at the middle until the distance between the inside corners at the knuckle joint (6-in. mark) is equal to the distance given for that angle under *Chord*. For example, in Fig. 23, the rule is shown to be open $3\frac{3}{32}$ in., therefore the angle formed is 30°

Angle Degrees	Chord Inches	Angle Degrees	Chord Inches
5	$\frac{17}{32}$	50	$5\frac{1}{16}$
10	$1\frac{1}{32}$	55	$5\frac{17}{32}$
15	$1\frac{9}{16}$	60	6
20	$2\frac{3}{32}$	65	$6\frac{7}{16}$
25	$2\frac{19}{32}$	70	$6\frac{7}{8}$
30	$3\frac{3}{32}$	75	$7\frac{5}{16}$
35	$3\frac{19}{32}$	80	$7\frac{23}{32}$
40	$4\frac{3}{32}$	85	$8\frac{3}{32}$
45	$4\frac{19}{32}$	90	$8\frac{1}{2}$

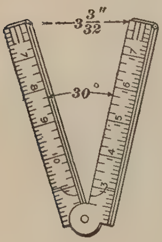


FIG. 23

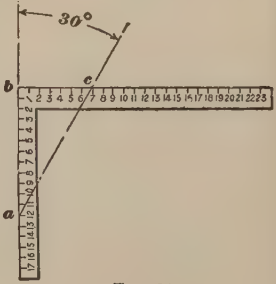


FIG. 24

To lay off an angle greater than 90°, subtract the angle from 180°: lay out the latter angle, extending one side past the vertex; the greater angle formed will be the one required.

By Steel Square.—To lay off any angle given in the table, by means of a steel square, set either blade or tongue of the square along the line *ab*, Fig. 24, marking the 12 in. point at *a*. Mark *c* at a distance from *b* equal to that given in the following table for the required angle, and draw *ac*; then the angle *bac* will be the angle sought, approximately correct. For example, to find an angle of 30°, the distance *bc* is $6\frac{15}{16}$ in.

Angle Degrees	Distance Inches	Angle Degrees	Distance Inches
5	$1\frac{1}{16}$	33° 42′ ($\frac{1}{3}$ pitch)	8
10	$2\frac{3}{32}$	35	$8\frac{13}{32}$
15	$3\frac{7}{32}$	40	$10\frac{1}{16}$
18° 25′ ($\frac{1}{6}$ pitch roof)	4	45 ($\frac{1}{2}$ pitch)	12
20	$4\frac{3}{8}$	50	$14\frac{5}{16}$
$22\frac{1}{2}$	$4\frac{31}{32}$	53° 7′ ($\frac{2}{3}$ pitch)	16
25	$5\frac{19}{32}$	55	$17\frac{1}{8}$
26° 33′ ($\frac{1}{4}$ pitch)	6	60	$20\frac{25}{32}$
30	$6\frac{15}{16}$		

STRUCTURAL DESIGN

SPECIFIC GRAVITY

The *specific gravity* of a solid or liquid body is the ratio between its weight and that of a like volume of distilled water at 39.1° F. If the solid is of irregular shape, its specific gravity may be found by weighing it in air and in water; the loss of weight in water is the weight of an equal volume of water; hence, if W is the weight in air, and W' the weight in water, the specific gravity is $\frac{W}{W-W'}$.

The weight of water in various conditions is given in the following table:

Weight per Cubic Foot in Pounds

Water, pure at 32° F	62.417
Water, pure at 39.1° F	62.425
Water, pure at 62° F	62.355
Water, pure at 212° F	59.700
Water, sea	64.080
Ice	57.400
Snow, fresh	5 to 12
Snow, wet	15 to 50

LOADS ON STRUCTURES

DEAD LOADS

Loads on buildings may be classed under three general divisions: *dead loads*, *live loads*, and *snow and wind loads*.

The *dead loads* consist of the weight of the materials composing the structure. For instance, the brickwork in the walls forms a portion of the dead load upon the footings; the materials in the floors impose a dead load upon the columns, etc. In order to figure the amount of the dead loads on

WEIGHTS AND SPECIFIC GRAVITIES OF METALS

Name of Metal	Weight per Cubic Inch Pounds	Weight per Cubic Foot Pounds	Specific Gravity
Aluminum	.096	166	2.66
Antimony	.242	418	6.70
Bismuth	.355	613	9.82
Brass, cast	.292	504	8.07
Brass, rolled	.302	523	8.38
Copper, cast	.319	550	8.81
Copper, rolled	.321	555	8.89
Gold, 24 carat	.697	1,204	19.29
Iron, cast	.260	450	7.21
Iron wrought	.277	480	7.69
Lead, commercial	.412	712	11.41
Mercury, 60° F	.490	846	13.55
Silver	.378	655	10.50
Steel	.283	490	7.85
Tin, cast	.265	458	7.34
Zinc	.253	437	7.00

structures and the members therein, the weight of the various materials used must be known, and the accompanying tables will be found useful.

WEIGHTS AND SPECIFIC GRAVITIES OF BUILDING MATERIALS, ETC.

Name of Material	Weight per Cubic Foot Pounds	Specific Gravity
Bluestone	160	2.56
Brick, pressed	150	2.40
Brick, common	125	2.00
Cement, Portland (packed)	100–120	1.60–1.92
Cement, Portland (loose)	70–90	1.12–1.44
Cement, Slag (packed)	80–100	1.28–1.60
Cement, Slag (loose)	55–75	.88–1.20
Chalk	156	2.50
Charcoal	15–34	.24–.54
Cinder concrete	110	1.76
Clay, ordinary	120–150	1.92–2.40
Coal, hard, solid	93.5	1.50
Coal, hard, broken	54	.867
Coal, soft, solid	84	1.35
Coal, soft, broken	54	.87
Coke, loose	23–32	.37–.51
Concrete, cement, stone, or gravel	140–155	2.24–2.48
Earth, rammed	90–100	1.44–1.60
Granite	165–170	2.64–2.72
Gravel	117–125	1.87–2.00
Lime, quick (ground loose)	53	.85
Limestones	170	2.72
Marble	164	2.62
Plaster of Paris (cast)	80	1.28
Sand	90–106	1.44–1.70
Sandstone	151	2.42
Shales	162	2.60
Slate	160–180	2.56–2.88
Terra cotta	110	1.76
Trap rock	170	2.72

In calculating the dead loads, there are certain weights that must be assumed. For instance, the weight of the floorbeams and girders are not known, because their size has not

WEIGHTS AND SPECIFIC GRAVITIES OF MASONRY

Masonry	Weight per Cubic Foot Pounds	Specific Gravity
Common brickwork, cement mortar..	130	2.08
Common brickwork, lime mortar	120	1.92
Granite or limestone rubble, dry.....	138	2.21
Granite or limestone rubble.........	150	2.40
Granite or limestone, dressed........	165	2.64
Pressed brickwork.................	140	2.24
Sandstone rubble..................	145	2.32
Terra-cotta masonry...............	112	1.79

WEIGHTS OF DRY WOODS

Name of Wood	Weight per Cubic Foot Pounds	Name of Wood	Weight per Cubic Foot Pounds
Evergreens		*Hardwoods*	
Cedar, canoe......	23	Beech............	42
Cedar, red........	30	Birch, red........	35
Cypress..........	29	Chestnut.........	28
Fir, balsam.......	23	Cherry...........	36
Fir, red of California............	29	Elm.............	34
Fir, white........	22	Gum, sweet.......	37
Hemlock.........	26	Hickory..........	51
Pine, Oregon......	32	Locust...........	42
Pine, long-leaf....	38	Maple, hard..... ..	43
Pine, short-leaf...	32	Oak, red..........	45
Pine, sugar.......	22	Oak, white	50
Pine, white.......	24	Poplar, yellow	26
Redwood, California............	26	Sycamore.........	35
Spruce, black.....	28	Walnut, black	38
Spruce, Norway ..	29	*Rare Woods*	
Spruce, Sitka.....	26	Boxwood.........	50
Spruce, white.....	25	Ebony...........	76
Hardwoods		Mahogany........	32–60
Ash, black........	39	Rosewood........	68
Ash, white........	39	Teak.............	50
Basswood.........	28	Walnut, Circassian	35
		Walnut, Persian..	36

APPROXIMATE WEIGHT OF BUILDING MATERIALS

Material	Average Weight Pounds per Square Foot
Corrugated galvanized iron, No. 20, unboarded	2¼
Copper, 16 oz., standing seam	1¼
Felt and asphalt, without sheathing	2 to 3
Glass, ⅛ in. thick	1¾
Hemlock sheathing, 1 in. thick	2½
Lead, about ⅛ in. thick	6 to 8
Lath-and-plaster ceiling (ordinary)	6 to 8
Neponset roofing felt, two layers	½
Plaster lath, ⅜ in. thick, with plaster	6
Spruce sheathing, 1 in. thick	2
Slate, 3/16 in. thick, 3 in. double lap	6¾
Slate, ⅛ in. thick, 3 in. double lap	4½
Shingles, 6″×18″, one-third to weather	2
Skylight of glass, 3/16 to ½ in., including frame	4 to 10
Slag roof, 4-ply	4
Tin, IX	¾
Tiles (plain), 10½″×6¼″×⅝″—5¼″ to weather	18
Tiles (Spanish), 14½″×10½″—7¼″ to weather	8½
White-pine sheathing, 1 in. thick	2½
Yellow-pine sheathing, 1 in. thick	4

as yet been determined; likewise, the dimensions of the columns and many other structural details are unknown. The assumed

WEIGHT OF HOLLOW TILE

Kind	Span Feet	Thickness Inches	Weight Pounds per Square Foot
Dense-tile flat arch	4 to 7	6 to 12	22 to 42
Dense-tile partition		3 to 6	15 to 24
Porous-tile partition		3 to 6	17 to 26
Porous-tile ceiling		2 to 4	12 to 20
Porous-tile roofing		2 to 4	12 to 22

weights are obtained by approximating the dimensions of the parts of the structure and estimating their weights. After the structure has been designed, the actual dead loads should be checked, to make sure they approximate closely to those assumed. If any considerable variation is found, it can be taken care of by increasing or diminishing the sizes already determined.

WEIGHTS OF FLOORS, PARTITIONS, AND ROOFS

Description	Pounds per Square Foot
Floors, Including Weight of Beams	
Wooden, 2″×10″ joists, 1 floor, plaster ceiling	11 to 14
Wooden, 2″×12″ joists, 2 floors, plaster ceiling	14 to 17
Hollow tile, end or side construction, 2 floors, ceiling	55 to 70
Hollow tile, segmental, 6-in. to 8-in. tile, 1 floor, ceiling on arch	60 to 70
Hollow tile, Natco, 4-in. to 12-in., 1 floor, ceiling	60 to 90
Hollow tile and concrete beams, 4-in. to 15-in., 2 floors, ceiling	65 to 135
Brick-arch, 4-in. and 8-in., 1 floor, ceiling	75 to 115
Concrete slabs, top slab, 2 floors, ceiling, hung	65 to 90
Concrete slabs, bottom slab, 2 floors, ceiling	70 to 115
Partitions, Plastered Both Sides	
Stud, 4-in.	15 to 20
Terra cotta, 3-in. blocks	25 to 27
Terra cotta, 4-in. blocks	26 to 28
Terra cotta, 5-in. blocks	34 to 36
Gypsum, 3-in. blocks	18
Gypsum, 4-in. blocks	20
Gypsum, 6-in. blocks	25
Roofs, Including Weight of Rafters	
Shingles, on lath and wooden rafters	6 to 10
Tin on boards and felt and wood rafters	6 to 8
Slate on lath and wood rafters	10 to 15
Tar and gravel on boards and wood rafters	10 to 14
Corrugated iron and wood rafters	4 to 6
Tile on felt and boards and wood rafters	15 to 22

NOTE.—If roofs are lathed and plastered on the underside of rafters, add 6 lb. per sq. ft. to the weight given. If the ceiling is hung from the rafters or floor beams on wood or metal framing, add 9 to 10 lb. per sq. ft.

Weight of Fireproof Floors.—In figuring the dead load for any system of floor construction, it is necessary to calculate carefully the total weight of the elements composing the system, which are the arches, filling, flooring, ceiling, and the steel construction. The weight of fixed or permanent partitions should always be taken into account, and the beams, etc. carrying them, proportioned accordingly. Where the partitions are movable, an additional weight of, say, 20 lb. per sq. ft., should be added to the dead load on the entire floor area.

Where only the approximate dead load due to the floor, partition, or roof construction is desired, the preceding table will be of use. In this table, the wooden floors and roof sheathing are taken as $\frac{7}{8}$ in. thick; cinder fill is estimated at 60 lb. per cu. ft.; and cinder concrete, at 110 lb. per cu. ft.

LIVE LOADS

The *live load* is variable, and consists of the weight of people, furniture, stocks of goods, machinery, etc. The amount of this load, which should be added to the dead load, depends on the use to which the building is to be put. Where the floor is required to support a considerable live load, concentrated at a particular place, such as a heavy safe or piece of machinery, special provision should be made in the floor construction for it. The preceding table gives the live loads per square foot sometimes used in building construction, although the decision in each individual case depends on local conditions and the experience of the designer.

LIVE LOADS OF BUILDINGS

Type of Building	Pounds per Square Foot
Dwellings, offices, hotels, and apartment houses	40 to 70
Theaters, churches, ballrooms, and drill halls	80 to 120
Factories	150 up
Warehouses	150 to 250 up

A live load of 70 lb. per sq. ft. will seldom be attained in dwellings; but, as city houses are liable to be used for other than dwelling purposes, it is not generally advisable to use a lighter load. In country houses, hotels, etc., where economy demands it, and the intended use for a long time is certain, a live load of 40 lb. per sq. ft. of floor surface is ample for all rooms not used for public assembly. For such rooms, a live load of 80 lb. per sq. ft. will usually be sufficient, as experience shows that a floor is not apt to be crowded with a greater weight than this. If the desks and chairs are fixed, as in a schoolroom or church, a live load over 40 to 50 lb. will never be attained.

Office-building floors have been designed for a live load ranging from 20 to 150 lb. per sq. ft., but a conservative practice is to use about 70 lb. per sq. ft. An investigation of the live loads in over 200 office buildings in Boston showed that the greatest live load in any office was 40 lb. per sq. ft., and the 10 heaviest loaded offices averaged 33 lb. per sq. ft., the average live load for the entire number of offices being about 17 lb. per sq. ft.

Retail stores should have floors proportioned for a live load of 100 lb. and upwards; and, for wholesale stores, machine shops, etc., a live load of at least 150 lb. per sq. ft. should be figured on. The static load in factories seldom exceeds 40 to 50 lb. per sq. ft. of floor surface, and usually a live load of 100 lb., including the effect of vibrations due to moving machinery, is ample. The conservative rule is, in general, to assume loads not less than the foregoing, and to be sure that the beams are proportioned to avoid excessive deflection. Stiffness is as important a factor as mere strength.

In designing the floors of office buildings, or buildings of like character, it is good practice to figure the full live load on the floor joists or beams, but to consider only a certain percentage as coming upon the girders, columns, and foundations, on the assumption that all of the floors will not be fully loaded at the same time. This percentage should be carefully considered in each case; and the amounts will depend on the height of the building in question and the judgment of the designer.

In proportioning the foundations of hotels, office buildings, etc., a reduced live load is used, but full live load should be taken for warehouses. In buildings with heavy machinery causing much vibration, it is good practice to double the estimated live load.

SNOW AND WIND LOADS

Snow Loads.—Data in regard to snow and wind loads are necessary in connection with the design of roof trusses. Snow loads are generally estimated in pounds per square foot of horizontal projection of roof, and as acting in a vertical direction. For slopes of 20° and under, a snow load of 25 lb. per sq. ft. of horizontal projection of roof is a safe allowance. This load may be reduced 1 lb. for each additional degree of increase in the slope of the roof. When snow guards are used, the reduction should be only $\frac{3}{4}$ lb. for each additional degree of rise over 20°. When the pitch is 45° or over, the snow load may be neglected, if snow guards are not used, as the action of the wind, together with the slope of the roof prevent the accumulation of snow. Snow loads naturally vary with the climate and latitude. The maximum allowances that may be made in different localities in the United States are given in the following table.

MAXIMUM ALLOWANCE FOR SNOW LOADS

Locality	Pounds per Square Foot
Southern States and Pacific Slope	5
Baltimore, Cincinnati, and St. Louis	10
Philadelphia, Pittsburg, and Wheeling	15
New York City, Chicago, and Cleveland	20
Boston, Albany, Buffalo, and St. Paul	25
Northern New England, Michigan, and Minnesota	30

Wind Loads.—The wind is considered as blowing in a horizontal direction, but the resulting pressure on the roof is generally taken normal (at right angles) to the slope. The greatest wind velocity recorded in the United States is 100 mi. per hr. Calculations show that a wind of that force will exert a pressure against a vertical surface of about 50 lb. per sq. ft., but in practice 40 lb. per sq. ft. is taken as the maximum. The following table shows the pressures exerted against a vertical plane surface by the wind at different velocities.

The wind pressure upon a cylindrical surface is one-half that upon a flat surface of the same height and width. As the wind is considered as traveling in a horizontal direction, it is evident that the more nearly vertical the slope of the roof, the greater will be the pressure, and the more nearly horizontal the slope, the less will be the pressure. In the following table is given the pressure exerted upon roofs of different slopes, by a wind pressure of 40 lb. per sq. ft. on a vertical plane, which is equivalent in intensity to a violent hurricane.

TABLE OF WIND PRESSURES

Strength of Winds	Miles per Hour	Feet per Minute	Feet per Second	Force, in Pounds per Square Foot
Hardly perceptible	1	88	1.47	.005
Just perceptible	2	176	2.93	.020
	3	264	4.40	.044
Gentle breeze	4	352	5.87	.079
	5	440	7.33	.123
Pleasant breeze	10	880	14.67	.492
	15	1,320	22.00	1.107
Brisk gale	20	1,760	29.33	1.968
	25	2,200	36.67	3.075
High wind	30	2,640	44.00	4.428
	35	3,080	51.33	6.027
Very high wind	40	3,520	58.67	7.872
	45	3,960	66.00	9.963
Storm	50	4,400	73.33	12.300
Great storm	60	5,280	88.00	17.712
	70	6,160	102.67	24.108
Hurricane or cyclone	80	7,040	117.33	31.488
	100	8,800	146.67	49.200

In addition to wind and snow loads upon roofs, the weight of the principals or roof trusses, including the other features of the construction, should be figured in the estimate. For light roofs having a span of not over 50 ft., and not required

WIND PRESSURE ON ROOFS, IN POUNDS PER SQUARE FOOT

Rise in Inches per Foot of Run	Angle With Horizontal	Pitch, Proportion of Rise to Span	Wind Pressure Normal to Slope
4	18° 26′	$\frac{1}{6}$	16.8
6	26° 34′	$\frac{1}{4}$	23.8
8	33° 41′	$\frac{1}{3}$	29.2
12	45° 0′	$\frac{1}{2}$	36.2
16	53° 8′	$\frac{2}{3}$	38.8
18	56° 19′	$\frac{3}{4}$	39.4
24	63° 26′	1	40.0

to support any ceiling, the weight of the steel construction may be taken at 5 lb. per sq. ft.; for greater spans, 1 lb. per sq. ft. should be added for each 10 ft. increase in the span.

STRENGTH OF MATERIALS

Stress.—Stress is the cohesive force by which the particles of a body resist the external load that tends to produce an alteration in the form of the body. Stress is always equal to the effective external force acting upon the body; thus, if a bar is subjected to a direct pulling force of 1,000 lb. a stress of 1,000 lb. is induced in the bar. *Unit stress* is the stress per square inch of section. For instance, if the bar just mentioned is 1 in.×2 in. in section, the unit stress of the bar will be 1,000÷2 (sectional area in square inches) = 500 lb.

Tensile stress is produced when the external forces tend to stretch a body, or pull the particles away from one another. A rope by which a weight is suspended is an example of a body subjected to tensile stress. *Compressive stress* is produced when the forces tend to compress the body, or push the particles closer together. A post or column of a building is subjected to compressive stress. *Shearing stress* is produced when the forces tend to cause the particles in one section of a body to slide over those of the adjacent section. A steel plate acted on by the knives of a shear, or a beam carrying a load, is subjected to shearing stress. The stresses in any structure may be reduced to combinations of tensile, compressive, and shearing stresses.

Deformation.—When a body is subjected to stress, there is a change in its dimensions or shape, which is called a deformation. The deformation in a unit length of a body is the unit deformation and is found by dividing the total deformation by the length in which it occurs.

Elastic Properties and Strength.—When a body is first subjected to a stress and then the forces or loads causing the stress are removed, the body will return to its original dimensions, provided the unit stress has not exceeded a certain value called the *elastic limit.*

For unit stresses below the elastic limit, the ratio of the unit stress to the corresponding unit deformation is a constant, called the *modulus of elasticity*. If f represents the unit stress, k the corresponding unit deformation, and E the modulus of elasticity of the material,

$$E=\frac{f}{k}$$

The unit stress obtained by dividing the maximum load that a specimen of material can sustain by the original cross-sectional area of the specimen is called the *ultimate strength* of the material. When a beam is loaded to failure, the maximum unit stress in the material is called the *modulus of rupture.*

Average values of the elastic limit in tension or compression, the modulus of elasticity, the ultimate strength, and the modulus of rupture of the important metals used in construction are given in the table on page 77, and the ultimate compressive strength and modulus of rupture of stone and brick, in the table on page 78.

Allowable Unit Stresses.—Generally the allowable unit stress to be used under given conditions is fixed by specifications or building codes. However, it is sometimes determined by dividing the ultimate strength of the material by a

STRENGTH AND PROPERTIES OF METALS

Material	Ultimate Strength Pounds per Square Inch			Modulus of Elasticity Pounds per Square Inch		Elastic Limit Pounds per Square Inch	Modulus of Rupture Pounds per Square Inch
	Tension	Com-pression	Shear	Tension or Compression	Shear		
Cast iron	20,000	80,000	18,000	15,000,000	6,000,000		30,000
Steel castings	70,000	70,000	60,000	30,000,000	11,000,000	32,000	65,000
Structural aluminum	60,000	.....	36,000	10,300,000	3,800,000	37,000	60,000
Structural steel	64,000	64,000	50,000	30,000,000	11,000,000	35,000	64,000
Wrought iron	50,000	50,000	40,000	27,000,000	10,000,000	30,000	45,000

STRENGTH OF STONE AND BRICK

Material	Crushing Strength Pounds per Square Inch	Modulus of Rupture Pounds per Square Inch
Granite	15,000	1,500
Sandstone	10,000	1,200
Limestone	10,000	1,200
Marble	12,000	1,400
Common brick	4,000	500 to 1,000
Pressed brick	8,000	600 to 1,200
Paving brick	10,000	1,500 to 2,500

suitable number called a factor of safety. Average values for the factor of safety to be used under various conditions are given in the following table.

FACTORS OF SAFETY

Material	Gradually Applied Loads	Suddenly Applied Loads	Shocks
Brick and stone	15	25	30
Cast iron	6	15	20
Steel castings	6	8	20
Structural steel	4	6	10
Wrought iron	4	6	10

The allowable unit stresses, in pounds per square inch, for steel that are recommended by the American Institute of Steel Construction are as follows:

Tension on net section of rolled shapes or built-up members............................20,000

Tension on nominal area of cross-section of rivets. 15,000

Compression on gross section of columns for which ratio of unsupported length l to radius of gyration r is less than 120:	$17{,}000-.485\left(\frac{l}{r}\right)^2$
Compression on gross section of columns for which ratio of l to r exceeds 120:	$\dfrac{18{,}000}{1+\frac{1}{18{,}000}\left(\frac{l}{r}\right)^2}$
Compression on plate-girder stiffeners	20,000
Compression on webs of rolled sections	24,000
Tension on extreme fibers of rolled shapes or built-up members in bending	20,000
Compression on extreme fibers of rolled shapes or built-up members in bending when ratio of unsupported length l' to width b of compression flange is less than 15	20,000
Compression on extreme fibers of rolled shapes or built-up members when ratio of l' to b is greater than 15:	$\dfrac{22{,}500}{1+\frac{1}{1{,}800}\left(\frac{l'}{b}\right)^2}$
Tension or compression in extreme fibers of pins in bending	30,000
Shearing on gross area of webs of beams and plate girders	13,000
Shearing on rivets	15,000
Shearing on pins or turned bolts in reamed or drilled holes	15,000
Shearing on unfinished bolts	10,000
Bearing on rivets or turned bolts in reamed holes, when rivets or bolts are in double shear	40,000
Bearing on rivets or turned bolts in reamed holes, when rivets or bolts are in single shear	32,000

Bearing on unfinished bolts in double shear	25,000
Bearing on unfinished bolts in single shear	20,000
Bearing on pins	32,000
Bearing on contact area of member with milled surface	30,000
Bearing on contact area of fitted stiffener	27,000

Bearing per linear inch of roller, 600 times the diameter of the roller in inches.

For combined stresses due to wind and other loads, the values may be increased 33⅓%, provided the section thus found is not less than that required by the dead and live loads alone.

Allowable unit stresses for timbers depend on the species and quality of the wood. Safe pressures for masonry are given in the following table.

SAFE PRESSURES FOR MASONRY

Material	Safe Pressure Pounds per Square Inch
Common brick, in lime mortar	100
Rubble masonry, in lime mortar	150
Common brick, in portland-cement mortar	200
Rubble masonry, in portland-cement mortar	200
Hard brick, in portland-cement mortar	250
Sandstone ashlar, in portland-cement mortar	400
Limestone ashlar, in portland-cement mortar	500
Concrete, 1:2:4 or 2,000-pound at 28 days	600
Granite ashlar, in portland-cement mortar	800

COMPOSITION AND RESOLUTION OF FORCES

CONCURRENT FORCES

Definitions.—The *resultant* of two or several forces acting on a body is the single force that, if acting alone, would produce the same effect as the several forces combined. The latter forces are called *components* with respect to the resultant.

Composition of forces is the process of finding the resultant when the components are known. The converse process of finding the components when the resultant is given, is called *resolution of forces*.

Parallelogram of Forces. If two forces, as F_1 and F_2, Fig. 1, are represented in magnitude and direction by two lines, as OA and OB, their resultant R will be represented in magnitude and direction by the diagonal OC of the parallelogram $OACB$ which is constructed by drawing BC and AC parallel to OA and OB, respectively.

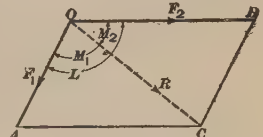


FIG. 1

The resultant R can also be determined by the formula $R=\sqrt{F_1^2+F_2^2+2F_1F_2\cos L}$, and the angles M_1 and M_2 that R makes with F_1 and F_2, respectively, may be found by the formulas,

$$\sin M_1=\frac{F_2 \sin L}{R}$$

and

$$\sin M_2=\frac{F_1 \sin L}{R}$$

For *rectangular components* $L=90°$. The formulas then become:

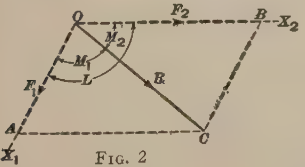


FIG. 2

$$R=\sqrt{F_1^2+F_2^2}$$

$$\sin M_1=\frac{F_2}{R}$$

$$\sin M_2=\frac{F_1}{R}$$

Resolution of Forces. A given force may have an innumerable number of combinations of components. The problem is, however, determinate when the directions of the components are given.

Let OC, Fig. 2, represent in magnitude and direction the force R acting at O, and let it be required to find its components in the directions OX_1 and OX_2. Draw from C, lines parallel to these directions meeting OX_1 at A and OX_2 at B. Then, OA and OB are the required components F_1 and F_2. They may be determined also by the formulas

$$F_1=\frac{R \sin M_2}{\sin (M_1+M_2)}$$

and

$$F_2=\frac{R \sin M_1}{\sin (M_1+M_2)}$$

When F_1 and F_2 are perpendicular to each other, then $M_1+M_2=90°$

and

$$F_1=R \sin M_2$$
$$F_2=R \sin M_1$$

When the components are horizontal and vertical,

$$X=F \cos H$$
$$Y=F \sin H$$

in which F = given force;

H = angle that force makes with horizontal;

X = horizontal component of force;

Y = vertical component of force.

Triangle of Forces.—In Fig. 1, AC is equal and parallel to OB, and therefore AC as well as OB represents the force F_2. Hence, the resultant of F_1 and F_2 can be determined by merely drawing the triangle OAC as follows: Lay off OA representing F_1, from its end A lay off AC representing F_2, and draw the line from O to C, completing the triangle OAC. Since BC is equal and parallel to OA, OC can be determined by constructing the triangle OBC instead of the triangle OAC. Either of the triangles OAC or OBC is called a triangle of forces.

Polygon of Forces.—The following rule may be applied for finding the resultant of any number of concurrent forces:

Rule.—*Beginning from any convenient point, lay off the given forces to any suitable scale in continuous order, that is, start each force at the end of the preceding one. Then, complete the polygon of forces by drawing a line from the beginning or origin of the first force to the end of the last force. The length of this line, measured to the scale used for laying off the forces, is the magnitude of the required resultant.*

Balanced Concurrent Forces.—When a system of forces is balanced, the lines representing the forces must form a closed figure when laid off in a polygon of forces.

Problems involving balanced systems of forces may be divided into two classes. In the first class, it is required to find the magnitude and direction of one force of the system; in the second class it is required to determine the magnitudes of two forces whose lines of action are known.

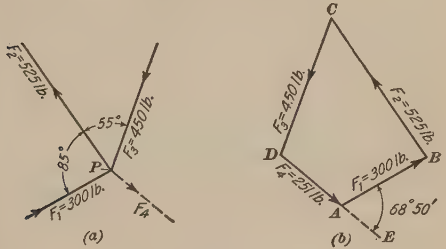


FIG. 3

To solve a problem of the first class, all the known forces are laid off in continuous order and the polygon of forces is closed by drawing a line from the end of the last force to the origin of the first force; the closing line represents the required force. In solving a problem of the second class, all the known forces are also laid off in continuous order. However, in this case, the polygon of forces is completed by drawing first an unlimited line through the origin of the first known force parallel to the line of action of one unknown force, drawing another line through the end of the last known force parallel to the line of action of the other unknown force, and continuing the two lines until they intersect. The two lines thus determined represent the required forces.

EXAMPLE 1.—The point P, Fig. 3 (a), is held in equilibrium by the four forces F_1, F_2, F_3, and F_4. The magnitudes and directions of F_1, F_2, and F_3 being as shown, find the magnitude of F_4 and the angle that F_4 makes with F_1.

SOLUTION.—The polygon of forces is constructed in Fig. 3 (*b*). Starting at any point A, the line AB is first laid off to scale to represent F_1, BC is next drawn in continuous order with AB to represent F_2, and CD is then laid off in continuous order with BC to represent F_3. Since F_4 must complete the polygon of forces, the magnitude of F_4 is the length of DA, which is 251 lb.

The direction of DA is as indicated by the arrowhead, the force being in continuous order with CD and AB. The angle BAE between F_1 and F_4 is 68° 50′.

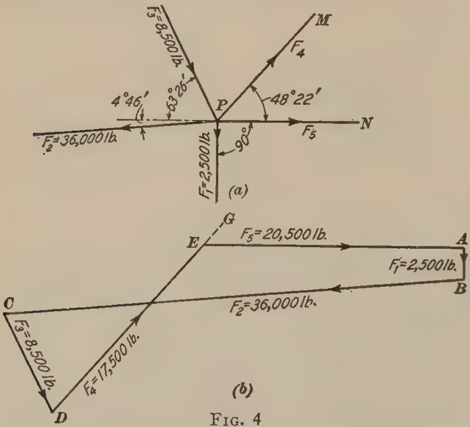


FIG. 4

EXAMPLE 2.—In Fig. 4 (*a*) are shown the forces acting at the joint P in a roof truss, the joint being in equilibrium. The weight F_1 is 2,500 pounds and the forces F_2 and F_3 were found by previous calculations to have the magnitudes and directions indicated. Determine the magnitudes and directions of F_4 and F_5, which act along the lines PM and PN, respectively.

SOLUTION.—First, the lines AB, BC, and CD representing the known forces F_1, F_2, and F_3 are laid off in continuous order to scale, as shown in Fig. 4 (*b*). Then, since the lines representing F_4 and F_5 must complete the polygon of forces, and since these lines must be parallel to the known lines of action of the forces, the line *DG* of unlimited length is drawn parallel to *PM* in (*a*) and the line *AE* is drawn parallel to *PN*. The required polygon is *ABCDEA*, and F_4 and F_5 are represented by *DE* and *EA*, respectively. The magnitude of F_4, as indicated by the length of *DE*, is 17,500 lb., and the magnitude of F_5, or the length of *EA*, is 20,500 lb.

The forces in the force polygon must be in continuous order and, therefore, the directions of F_4 and F_5 are as shown by the arrowheads in (*b*). Hence, both forces act away from *P* as indicated by the arrowheads on their lines of action in (*a*).

Equations of Equilibrium.—For every balanced system of concurrent forces, the algebraic sum of the components in any direction is zero. In solving problems, it is customary to consider two directions at right angles to each other.

The symbol of summation Σ, read *sigma*, is often used to indicate the algebraic addition of a series of similar quantities. If, for example, several quantities are denoted by X_1, X_2, X_3, X_4, etc., their algebraic sum $X_1+X_2+X_3+X_4+\ldots$ is denoted by the expression ΣX, read *sigma X*. With this notation, the algebraic sum of the components, X_1, X_2, etc., of any number of forces may be denoted by ΣX.

The relations among the components of the forces of a balanced system may be expressed by the equations

$$\Sigma X = 0$$

and

$$\Sigma Y = 0$$

in which ΣX and ΣY = algebraic sums of components of given forces.

PARALLEL FORCES

Moments of Forces.—The moment of a force about a point is the product obtained by multiplying the magnitude of the force by the perpendicular distance from the point to the line of action of the force. In Fig. 5, the moment of *F* about the point *C* is Fp; and about the point C_1 it is Fp_1.

The point to which a moment is referred, or about which a moment is taken, is called the *center of moments*, or *origin of* *moments.* The perpendicular p or p_1 from the origin of moments to the line of action of the force is called the *lever arm*, or simply the *arm*, of the force with respect to the origin. A moment is expressed in foot-pounds, inch-pounds, etc., according to the units to which the force and its arm are referred.

The moment is either positive or negative, depending on the direction in which the force tends to cause rotation. It is positive for clockwise motion, and negative for counter-clockwise motion. Thus, the moment of F about C is positive and the moment about C_1 is negative, because, if the arms p and p_1 were bars, the force would tend to rotate p in a clockwise direction about C, and p_1 in a counter-clockwise direction about C_1.

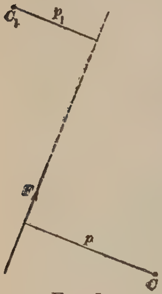


FIG. 5

Resultant of Parallel Forces.—The resultant of any system of parallel forces is equal to the algebraic sum of the given forces. The distance from any point to the line of action of the resultant is found by the formula

$$p_r = \frac{\Sigma M}{R}$$

in which p_r = distance from any point to resultant;

ΣM = algebraic sum of moments of forces about that point as a center of moments;

R = resultant of system.

Balanced Parallel Forces.—In a balanced system of parallel forces, the algebraic sum of the forces must be equal to zero and the algebraic sum of the moments of the forces about any point as a center must also be zero. These conditions may be expressed by the formulas

$$\Sigma F = 0$$

and

$$\Sigma M = 0$$

in which ΣF = algebraic sum of forces;

ΣM = algebraic sum of moments about any point.

Two equal parallel forces acting in opposite directions along different lines form a couple, in which ΣF is zero but ΣM is not zero. Hence, a couple is not a balanced system, but tends to cause rotation of the body on which it acts.

PROPERTIES OF SECTIONS

CENTER OF GRAVITY

Plane Figures.—The center of gravity of a body is the point through which the force representing the weight of the entire body passes regardless of the position of the body.

The center of gravity of a *parallelogram* is at the intersection of the diagonals or midway between either pair of parallel sides. That of a *triangle* is at the intersection of lines drawn from the vertexes to the middle points of the opposite sides; the perpendicular distance from any side to the center of gravity of the triangle is equal to one-third the altitude when that side is considered as the base.

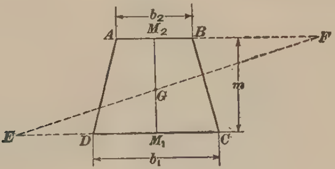


FIG. 6

The center of gravity of any *trapezoid* can be located by the following method:

Rule.—*Draw the median line joining the middle points of the bases. Produce the bases in opposite directions, making the prolonged part of each base equal to the other base. Draw a line joining the ends of the prolonged parts. The point where this line intersects the median line is the required center of gravity.*

To find the center of gravity of the trapezoid in Fig. 6, lay off $BF = DC$ and $DE = AB$; the center of gravity is at the intersection of EF with $M_1 M_2$, the line joining the middle points of the parallel sides. The perpendicular distance from the longer base to the center of gravity may be found by the formula

$$y=\frac{m}{3}\times\frac{b_1+2b_2}{b_1+b_2}$$

in which y = perpendicular distance from longer base to center of gravity;
m = altitude of trapezoid;
b_1 = longer base;
b_2 = shorter base.

The center of gravity of a symmetrical plane figure lies on the axis of symmetry. If there are two axes of symmetry, the center of gravity is located at their point of intersection. The center of gravity of a *circle* or an *ellipse* is at the geometrical center of the figure.

For a *circular sector*,

$$y_c=\frac{240r\sin\frac{1}{2}L}{\pi L}$$

in which r = radius of sector;
L = central angle;
y_c = distance from center to center of gravity of sector.

In the denominator of the second member of this formula, the angle L is expressed in degrees and a decimal part of a degree.

For a *circular segment*,

$$y_c=\frac{240r\sin^3\frac{1}{2}L}{\pi L-180\sin L}$$

in which y_c = distance from center to center of gravity of segment;
r = radius of segment;
L = central angle of segment.

In the quantity πL, the angle L is expressed in degrees and a decimal part of a degree.

To compute the perpendicular distance from a reference line to the center of gravity of a complex figure, proceed as follows: Divide the figure into elementary parts whose areas can be found easily and whose centers of gravity can be located by the methods just described. Find the area of each part and the perpendicular distance from the reference line to its center of gravity, and apply the formula

$$p_r = \frac{\Sigma M}{A}$$

in which p_r = perpendicular distance from any reference line to center of gravity of figure;

ΣM = algebraic sum of moments of areas of parts of figure with respect to that reference line;

A = area of entire figure.

EXAMPLE 1.—Locate the center of gravity of the angle section $OABCDE$, Fig. 7, by determining its perpendicular distances from the edges OA and OE.

SOLUTION.—The given figure is first divided into the rectangles $ABHO$ and $CDEH$ by prolonging BC to H. The area of $ABHO$ is $AO \times AB = 6 \times .75 = 4.5$ sq. in., the area of $CDEH$ is $EH \times ED = (3.5 - .75) \times .75 = 2.06$ sq. in., and the area of the angle is $4.5 + 2.06 = 6.56$ sq. in.

The center of gravity of the rectangle $ABHO$ is at G_1 and that of the rectangle $CDEH$ is at G_2. To locate the center of gravity G of the entire angle, the perpendicular distances LG and PG from the edges OA and OE, respectively, are determined.

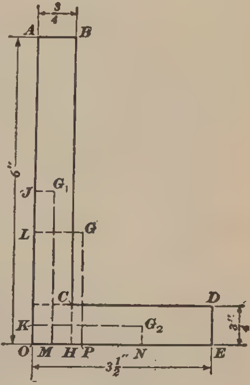


FIG. 7

The arm of the area of $ABHO$ about the line OA is $JG_1 = \frac{1}{2}OH = \frac{1}{2} \times .75 = .375$ in., and the arm of the area of $CDEH$ about OA is $KG_2 = OH + \frac{1}{2}HE = .75 + \frac{3.5 - .75}{2} = 2.13$ in. Then, the distance LG from OA to the center of gravity of the given figure is found by the formula

$$p_r=\frac{\Sigma M}{A}=\frac{4.5\times.375+2.06\times2.13}{6.56}=.93\text{ in.}$$

With respect to OE as a reference line, the arm of the area of $ABHO$ is $MG_1=\frac{1}{2}OA=3$ in. and the arm of the area of $CDEH$ is $NG_2=\frac{1}{2}DE=.375$ in. Then, the distance PG from OE to the center of gravity is

$$p_r=\frac{\Sigma M}{A}=\frac{4.5\times3+2.06\times.375}{6.56}=2.18\text{ in.}$$

Example 2.—Find the center of gravity of the section shown in Fig. 8.

Solution.—The center of gravity is on the line YY, which is an axis of symmetry. To find the distance y, divide the section into angles and plates and take moments about XX. The areas and centers of gravity of the angles might be located by the preceding principles or taken from a manufacturer's handbook. They are: for the $4''\times4''\times\frac{1}{2}''$ angle, area $=3.75$ sq. in. and distance from center of gravity to back of angle $=1.18$ in.; for the $3\frac{1}{2}''\times3\frac{1}{2}''\times\frac{1}{2}''$ angle, area $=3.25$ sq. in. and distance from center of gravity to back of angle $=1.06$ in. Hence, the moment of the bottom angles is $2\times3.75\times1.18=8.85$ and that of the top angles is $2\times3.25(15-1.06)=90.61$. The moment of the two web plates is $2\times15\times\frac{1}{2}\times7.5=112.5$, and that of the cover-plate, $24\times\frac{1}{2}\times15.25=183.00$. The sum of the moments is $8.85+90.61+112.5+183.00=394.96$. The sum of the areas is $2\times3.25+2\times3.75+24\times\frac{1}{2}+2\times15\times\frac{1}{2}=41$ sq. in. Then, $y=394.96\div41=9.63$ in.

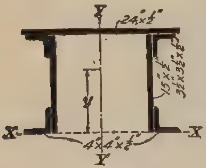


Fig. 8

Center of Gravity of Solids.—For a solid having three axes of symmetry, all perpendicular to each other, like a sphere, cube, right parallelopiped, etc., the point of intersection of these axes is the center of gravity.

For a cone or pyramid, draw a line from the apex to the center of gravity of the base; the required center of gravity is one-fourth the length of this line from the base, measured on the line.

MOMENT OF INERTIA

The moment of inertia of a plane figure about a given axis is the quantity obtained by multiplying each of the very small areas into which the figure may be conceived to be divided, by the square of the distance from the axis to its center of gravity, and adding the products. The moment of inertia is generally designated by the letter I.

Formulas for the values of I about an axis passing through the center of gravity of the section are given for various forms of sections in the accompanying table. Formulas and values of I for rolled-steel sections are given in the steel manufacturers' handbooks.

The moment of inertia of any section about any axis may be found by dividing the section into a number of parts, determining the moment of inertia of each part about the selected axis, and adding these values. In order to apply this method, it is usually necessary to find the moment of inertia of each part about an axis that does not pass through its center of gravity. This moment of inertia may be computed by the formula

$$I_x = I_0 + Ay^2$$

in which I_x = moment of inertia of any plane figure about any given axis;

I_0 = moment of inertia of figure about a parallel axis through its center of gravity;

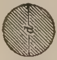
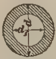
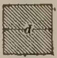
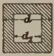
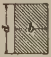
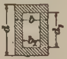
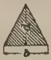
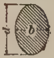
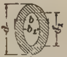
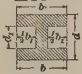
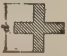
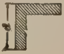
A = area of figure, in square inches;

y = distance between the two axes, in inches.

EXAMPLE 1.—Compute the moment of inertia of the L section in Fig. 7 about the line LG through its center of gravity, which is 2.18 in. from OE.

SOLUTION.—For the purpose of illustrating the general method, the section is considered to be composed of the rectangles $ABHO$ and $CDEH$. The moment of inertia of $ABHO$ about an axis JG_1 through its center of gravity is $I_0 = \frac{bd^3}{12}$ $= \frac{.75 \times 6^3}{12} = 13.5$, the area is $A = 6 \times .75 = 4.5$ sq. in., the dis-

MOMENTS OF INERTIA, ETC.

Name of Section.		I	$\frac{I}{c}$	r^2
Solid circular		$\frac{\pi d^4}{64}$	$\frac{\pi d^3}{32}$	$\frac{d^2}{16}$
Hollow circular		$\frac{\pi(d^4 - d_1^4)}{64}$	$\frac{\pi(d^4 - d_1^4)}{32d}$	$\frac{d^2 + d_1^2}{16}$
Solid square		$\frac{d^4}{12}$	$\frac{d^3}{6}$	$\frac{d^2}{12}$
Hollow square		$\frac{d^4 - d_1^4}{12}$	$\frac{d^4 - d_1^4}{6d}$	$\frac{d^2 + d_1^2}{12}$
Solid rectangular		$\frac{bd^3}{12}$	$\frac{bd^2}{6}$	$\frac{b^2}{12}$
Hollow rectangular		$\frac{bd^3 - b_1d_1^3}{12}$	$\frac{bd^3 - b_1d_1^3}{6d}$	$\frac{b^3d - b_1^3d_1}{12(bd - b_1d_1)}$
Solid triangular		$\frac{bd^3}{36}$	$\frac{bd^2}{24}$	$\frac{d^2}{18}$
Solid elliptical		$\frac{\pi bd^3}{64}$	$\frac{\pi bd^2}{32}$	$\frac{b^2}{16}$
Hollow elliptical		$\frac{\pi}{64}(bd^3 - b_1d_1^3)$	$\frac{\pi(bd^3 - b_1d_1^3)}{32d}$	$\frac{b^3d - b_1^3d_1}{16(bd - b_1d_1)}$
I-beam	 b d_1 $\frac{1}{2}b_1$ $\frac{1}{2}b_1$ d b	$\frac{bd^3 - b_1d_1^3}{12}$	$\frac{bd^3 - b_1d_1^3}{6d}$	$\frac{b^3d - b_1^3d_1}{12(bd - b_1d_1)}$
Cross with equal arms (approximate)				$\frac{d^2}{22.5}$
Angle with equal arms (approximate)				$\frac{d^2}{25}$

tance from *LG* to JG_1 is $y=3-2.18=.92$ in., and the moment of inertia about the axis *LG* is

$$I_x=I_o+Ay^2=13.5+4.5\times .92^2=17.31$$

For the rectangle *CDEH*, $I_0=\dfrac{2.75\times .75^3}{12}=.097$, $A=2.75\times .75=2.06$ sq. in., $y=2.18-.38=1.80$ in., and $I_x=.097+2.06\times 1.8^2=6.77$. Hence, the required moment of inertia is $17.31+6.77=24.08$.

Example 2.—Find the moment of inertia of the section shown in Fig. 8 about the neutral axis parallel to the cover-plate.

Solution.—The neutral axis passes through the center of gravity, which has been found to be 9.63 in. from the back of the bottom angles. The distances of the centers of gravity of the subdivisions of this section from the neutral axis are:

For the cover-plate $15.25-9.63$ . . . . $=5.62$
For the web-plates $9.63-7.50$ . . . . $=2.13$
For the $3\frac{1}{2}''\times 3\frac{1}{2}''\times\frac{1}{2}''$ **L**'s, $15.00-1.06-9.63$ . . $=4.31$
For the $4''\times 4''\times\frac{1}{2}''$ **L**'s, $9.63-1.18$ . . . . $=8.45$

The moments of inertia of the respective parts about their own neutral axes parallel to *XX* are:

For the cover-plate . . . . $\dfrac{24\times(\frac{1}{2})^3}{12}=\quad .25$

For the web-plates . . . . $\dfrac{2\times\frac{1}{2}\times 15^3}{12}=281.25$

From a steel manufacturer's handbook, the value of I for a $3\frac{1}{2}''\times 3\frac{1}{2}''\times\frac{1}{2}''$ **L** is found to be 3.64; and for a $4''\times 4''\times\frac{1}{2}''$ **L** it is 5.56. From these values, the moment of inertia of the entire section is, $I=.25+24\times\frac{1}{2}\times 5.62^2+281.25+2\times 15\times\frac{1}{2}\times 2.13^2+2\times 3.64+2\times 3.25\times 4.31^2+2\times 5.56+2\times 3.75\times 8.45^2=1{,}403$

SECTION MODULUS

The section modulus of any section can be found by dividing the moment of inertia of the section about an axis through its center of gravity by the distance from that axis to the extreme fibers of the section. Thus,

$$S=\frac{I}{c}$$

in which S = section modulus;

I = moment of inertia about axis through center of gravity;

c = distance, in inches, from axis to extreme fibers.

RADIUS OF GYRATION

The radius of gyration of a section may be found by dividing the moment of inertia of the section by its area, and taking the square root of the quotient, or by applying the following formula:

$$r=\sqrt{\frac{I}{A}}$$

in which r = radius of gyration about an axis through the center of gravity of the section, in inches;

I = moment of inertia of section about that axis;

A = area of section, in square inches.

BEAMS

REACTIONS, SHEARS, AND BENDING MOMENTS

Types of Beams.—A member that is subjected to loads acting at right angles to its axis, or inclined to the axis, and some distance from a support is called a beam. A *simple beam* is one that simply rests on two supports, one at each end. A *cantilever beam* has one end fixed and the other unsupported. An *overhanging beam* rests on two supports, but extends or overhangs beyond one or both supports. A *continuous beam* is one that is supported at the ends and rests on one or more intermediate supports. A *fixed beam* is rigidly supported at both ends.

In a simple or overhanging beam, the *span* is usually taken as the distance between centers of supports. In fixed beams it is the clear distance between faces of supports.

Reactions.—The forces exerted by the supports to hold a beam in equilibrium are called reactions. In the case of simple, cantilever, or overhanging beams for which all the loads and the reactions are parallel, the reactions can be computed by applying the formulas $\Sigma F=0$ and $\Sigma M=0$, as for any system of balanced parallel forces. For a cantilever beam, the reaction is obviously equal to the sum of the loads. For any simple or overhanging beam, either reaction can be found by taking the sum of the moments of all the loads about the other support and dividing the result by the span. Thus, in Fig. 1, the sum of the moments of the loads about A is $W_1a+W_2b+W_3c$ and

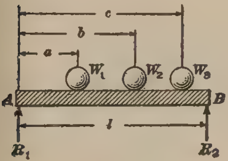


FIG. 1

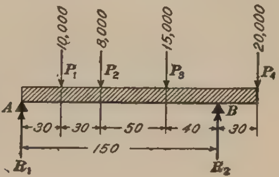


FIG. 2

$$R_2=\frac{W_1a+W_2b+W_3c}{l}$$

The reaction R_1 can be found in a similar manner by taking moments about B. The sum of the reactions, or R_1+R_2, should equal the sum of the loads, or $W_1+W_2+W_3$.

For the conditions shown in Fig. 2, R_1 is found by taking moments about B and R_2 by taking moments about A. Thus,

$$R_1=\frac{10{,}000\times120+8{,}000\times90+15{,}000\times40-20{,}000\times30}{150}$$

$$=12{,}800\text{ lb.}$$

and

$$R_2=\frac{10{,}000\times30+8{,}000\times60+15{,}000\times110+20{,}000\times180}{150}$$

$$=40{,}200\text{ lb.}$$

For a continuous beam with spans of equal length l and a uniform load w per foot of length, the reactions are found by multiplying the total load wl on the span between two adjacent supports by the proper value in the accompanying table.

REACTIONS FOR CONTINUOUS BEAMS OVER EQUAL SPANS

Coefficients of wl

Number of Spans	Number of Each Support									
	1st	2d	3d	4th	5th	6th	7th	8th	9th	10th
2	$\frac{3}{8}$	$\frac{10}{8}$	$\frac{3}{8}$							
3	$\frac{4}{10}$	$\frac{11}{10}$	$\frac{11}{10}$	$\frac{4}{10}$						
4	$\frac{11}{28}$	$\frac{32}{28}$	$\frac{26}{28}$	$\frac{32}{28}$	$\frac{11}{28}$					
5	$\frac{15}{38}$	$\frac{43}{38}$	$\frac{37}{38}$	$\frac{37}{38}$	$\frac{43}{38}$	$\frac{15}{38}$				
6	$\frac{41}{104}$	$\frac{118}{104}$	$\frac{100}{104}$	$\frac{106}{104}$	$\frac{100}{104}$	$\frac{118}{104}$	$\frac{41}{104}$			
7	$\frac{56}{142}$	$\frac{161}{142}$	$\frac{137}{142}$	$\frac{143}{142}$	$\frac{143}{142}$	$\frac{137}{142}$	$\frac{161}{142}$	$\frac{56}{142}$		
8	$\frac{153}{388}$	$\frac{440}{388}$	$\frac{374}{388}$	$\frac{392}{388}$	$\frac{386}{388}$	$\frac{392}{388}$	$\frac{374}{388}$	$\frac{440}{388}$	$\frac{153}{388}$	
9	$\frac{209}{530}$	$\frac{601}{530}$	$\frac{511}{530}$	$\frac{535}{530}$	$\frac{529}{530}$	$\frac{529}{530}$	$\frac{535}{530}$	$\frac{511}{530}$	$\frac{601}{530}$	$\frac{209}{530}$

Shear.—At any section of a beam, the resultant of the vertical forces on one side and that on the other side are equal, but act in opposite directions. Therefore, there is a tendency to shear the fibers of the beam at the section. When the loads and reactions are perpendicular to the axis of a beam, the shear at any cross-section of the beam is equal to the algebraic sum of the external forces (reactions and loads) on either side of the section. The shear is said to be positive when the resultant of the external forces on the left of the section is upward, and negative when it is downward. It is customary to determine the sign by considering the forces to the left of the section, upward forces being called positive and downward forces negative, and giving the shear the same sign as the algebraic sum of the forces. The shear in a beam changes at each section at which a load is applied.

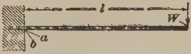
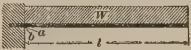
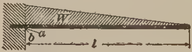
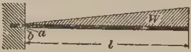
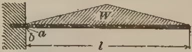
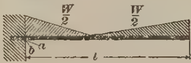
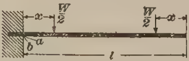
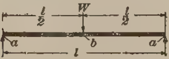
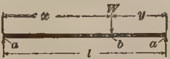
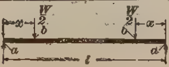
For the beam in Fig. 2, the shear between P_1 and P_2 is $12{,}800 - 10{,}000 = 2{,}800$ lb., between P_2 and P_3 it is $2{,}800 - 8{,}000 = -5{,}200$ lb., between P_3 and R_2, $-5{,}200 - 15{,}000 = -20{,}200$ lb., and between R_2 and P_4, $-20{,}200 + 40{,}200 = 20{,}000$ lb.

For any beam and any condition of loading, the greatest shear occurs at a support. For a cantilever beam, it is equal to the reaction and for a simple beam it is equal to the greater reaction. For an overhanging or continuous beam, it is often necessary to calculate the shear on each side of each support to determine the greatest value. Formulas for finding the maximum shear for various conditions are given on pages 98 and 99, the section of maximum shear in each case being at a.

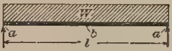
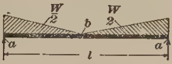
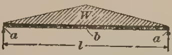
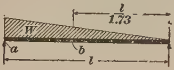
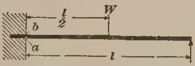
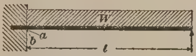
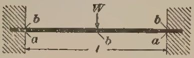
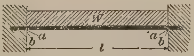
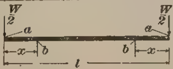
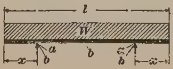
Shear Diagram.—In a shear diagram, a horizontal base line is first laid off to represent the length of the beam to a convenient scale. Then, the distances from either end of the beam to selected sections are laid off along the base line and the values of the shears at the corresponding sections are laid off perpendicular to the base line, positive shears being measured above the base line and negative shears below it. The line through the ends of these ordinates, which represents the variation in shear, is called the *shear line*.

The shear diagram for the beam in Fig. 3 (a) is shown in (b). The following principles should be kept in mind in constructing such a diagram.

FORMULAS FOR MAXIMUM SHEAR AND BENDING MOMENTS OF BEAMS

Case	Method of Loading	Maximum Shear	Maximum Moment
I		W	Wl
II		W	$\frac{Wl}{2}$
III		W	$\frac{Wl}{3}$
IV		W	$\frac{2Wl}{3}$
V		W	$\frac{Wl}{2}$
VI		W	$\frac{Wl}{2}$
VII		W	$\frac{Wl}{2}$
VIII		$\frac{W}{2}$	$\frac{Wl}{4}$
IX		$\frac{Wy}{l}$ or $\frac{Wx}{l}$	$\frac{Wxy}{l}$
X		$\frac{W}{2}$	$\frac{Wx}{2}$

TABLE—(*Continued*)

Case	Method of Loading	Maximum Shear	Maximum Moment
XI		$\frac{W}{2}$	$\frac{Wl}{8}$
XII		$\frac{W}{2}$	$\frac{Wl}{12}$
XIII		$\frac{W}{2}$	$\frac{Wl}{6}$
XIV		$\frac{2W}{3}$	$\frac{52Wl}{405}$
XV		$\frac{11}{16}W$	$\frac{3}{16}Wl$
XVI		$\frac{5}{8}W$	$\frac{Wl}{8}$
XVII		$\frac{W}{2}$	$\frac{Wl}{8}$
XVIII		$\frac{W}{2}$	$\frac{Wl}{12}$
XIX		$\frac{W}{2}$	$\frac{Wx}{2}$
XX		$\frac{Wx}{l}$ or $W\left(\frac{l-2x}{2l}\right)$	$\frac{Wx^2}{2l}$ or $\frac{W}{2}\left(\frac{l}{4}-x\right)$

1. A concentrated load or reaction, although really distributed over the beam for a short distance, is assumed to be applied at a point.

2. Under a portion of a beam that is not loaded or supported, the shear line is horizontal. Therefore, when a beam carries only concentrated loads, the shear has to be computed only at the supports and at sections under the loads.

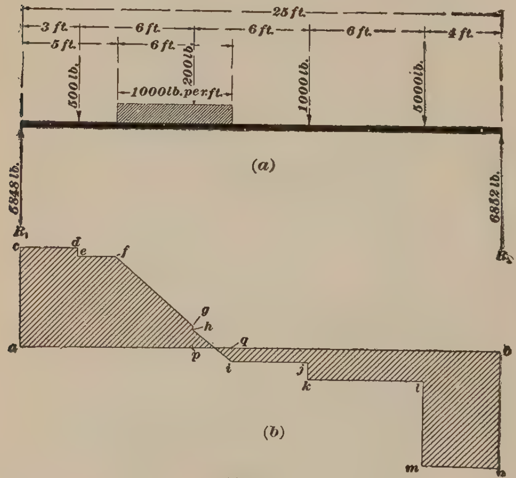


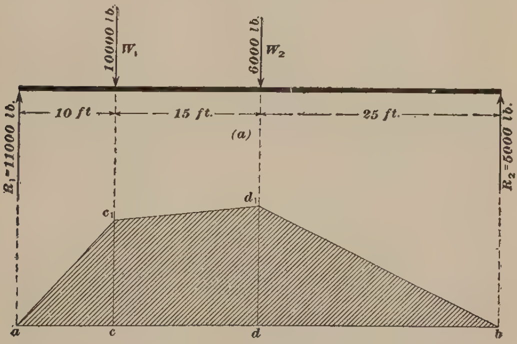
FIG. 3

3. The shear line is vertical under a concentrated load or reaction, and the height of the vertical step is equal to the concentrated load or reaction.

4. Under a uniform load, the shear line is straight but sloping downwards toward the right. Hence, when a beam or a part of a beam carries only a uniform load, the shear has to be calculated only at the ends of the load. If there are concen-

trated loads between the ends of a uniform load, the shear is computed also at those loads.

Thus, in Fig. 3 (*b*), *ac* represents the reaction R_1; the shear line is horizontal from *c* to *d*, because the corresponding portion of the beam is unloaded; there is a vertical drop from *d* to *e* representing 500 lb.; the portion *fg* slopes at the rate of 1,000 lb. per foot and, after the vertical step *gh* under the 200-lb. load, the part *hi* is parallel to *fg*. The remainder *ijklmnb* of the shear line consists of alternate horizontal and vertical portions.



(*b*)

FIG. 4

Bending Moment.—The algebraic sum of the moments of the forces to one side of a section of a beam, about the center of gravity of that section, is called the bending moment at the section. In determining the sign of the bending moment the usual custom is to assume that when forces to the left of the section are considered, clockwise moments are positive and counter-clockwise moments are negative, and the bending moment has the same sign as the algebraic sum of the moments. At the load P_3 in Fig. 2, the bending moment is $12{,}800 \times 110 - 10{,}000 \times 80 - 8{,}000 \times 50 = 208{,}000$ ft.-lb.

In a simple beam the bending moment is always positive, and in a cantilever it is always negative.

A bending moment diagram may be drawn in the same manner as a shear diagram. The moment diagram for the beam in Fig. 4 (*a*) is shown in (*b*). The bending moment at W_1 is $R_1 \times 10 = 110{,}000$ ft.-lb. and the distance cc_1 is laid off above the base line *ab* to represent that value. Similarly, dd_1 represents the bending moment at W_2. Under a portion of a beam that is not loaded or supported, the moment line is straight. Hence, when a beam carries only concentrated loads, the bending moment has to be computed only at the sections under those loads and at the supports. Moment lines never contain vertical steps, but there are breaks under the concentrated loads and reactions.

For a simple beam carrying a uniform load, the moment line is a parabola.

Maximum Bending Moment.—In a cantilever beam the maximum bending moment is at the reaction. In any other case, the bending moment is greatest at a section where the shear changes sign. For the beam in Fig. 3, the maximum bending moment occurs between *p* and *q* where the shear line crosses the base line *ab*. For the loads in Fig. 4, the shear changes sign under the 6,000-lb. load and the maximum moment occurs at that load, as shown in the moment diagram.

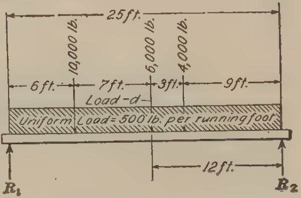


FIG. 5

EXAMPLE.—Calculate the maximum bending moment for the beam in Fig. 5.

SOLUTION.—First the reactions are computed.

$$R_2 = \frac{10{,}000 \times 6 + 6{,}000 \times 13 + 4{,}000 \times 16 + (500 \times 25) \times 12.5}{25}$$

$$= 14{,}330 \text{ lb.}$$

and $$R_1 = 18{,}170 \text{ lb.}$$

Just to the left of the load d, the shear is $18{,}170-10{,}000-500\times 13=1{,}670$ lb., and just to the right of the load it is negative. Hence, the bending moment is a maximum under that load. It is equal to $18{,}170\times 13-10{,}000\times 7-(500\times 13)\times 6.5=124{,}000$ ft.-lb.

The formulas for the maximum bending moments for various conditions are given in the table on pages 98 and 99, the section of maximum moment in each case being at b.

In a continuous beam with simply supported ends, the bending moment at any section is equal to the algebraic sum of the moments of the loads and reactions on either side of the section. If such a beam has equal spans and carries a uniform load, the maximum bending moments in it occur at the intermediate supports; these bending moments, which are negative, can be found for each support by multiplying the proper value in the following table by the product of the total load on one span and the length of the span, or by wl^2. In each span, the maximum positive bending moment occurs near the middle of the span; however, it is less than the maximum negative bending moments in the same span.

DESIGN OF BEAMS

Neutral Axis.—At a section of a beam where the bending moment is positive, compressive stresses are produced in the upper part of the beam and tensile stresses in the lower part; where the bending moment is negative, the upper part is in tension and the lower part in compression. In every section there is a line, called the neutral axis, in which there is neither tension nor compression. The neutral axis passes through the center of gravity of the section.

Flexure Formula.—The tensile and compressive unit stresses in a beam are proportional to their distances from the neutral axis. The resisting moment of a section is equal to the product of the unit stress in the extreme fibers and the section modulus of the section. Since the bending moment and the resisting moment are equal,

$$M=fS$$

or

$$M=\frac{fI}{c}$$

BENDING MOMENTS FOR CONTINUOUS BEAMS OVER EQUAL SPANS

Coefficients of wl^2

Number of Spans	Number of Each Support									
	1st	2d	3d	4th	5th	6th	7th	8th	9th	10th
2	0	$\frac{1}{8}$	0							
3	0	$\frac{1}{10}$	$\frac{1}{10}$	0						
4	0	$\frac{3}{28}$	$\frac{2}{28}$	$\frac{3}{28}$	0					
5	0	$\frac{4}{38}$	$\frac{3}{38}$	$\frac{3}{38}$	$\frac{4}{38}$	0				
6	0	$\frac{11}{104}$	$\frac{8}{104}$	$\frac{9}{104}$	$\frac{8}{104}$	$\frac{11}{104}$	0			
7	0	$\frac{15}{142}$	$\frac{11}{142}$	$\frac{12}{142}$	$\frac{12}{142}$	$\frac{11}{142}$	$\frac{15}{142}$	0		
8	0	$\frac{41}{388}$	$\frac{30}{388}$	$\frac{33}{388}$	$\frac{32}{388}$	$\frac{33}{388}$	$\frac{30}{388}$	$\frac{41}{388}$	0	
9	0	$\frac{56}{530}$	$\frac{41}{530}$	$\frac{45}{530}$	$\frac{44}{530}$	$\frac{44}{530}$	$\frac{45}{530}$	$\frac{41}{530}$	$\frac{56}{530}$	0

in which M = bending moment, in inch-pounds;
f = unit stress in extreme fibers, in pounds per square inch;
S = section modulus;
I = moment of inertia about neutral axis;
c = distance from neutral axis to extreme fibers, in inches.

Shearing Unit Stress in Beams.—The shearing unit stress at a cross-section of a beam is not uniformly distributed. It is zero at the extreme fibers and a maximum at the neutral axis. For an I beam or channel, it is customary to determine the maximum shearing unit stress by the formula

$$v=\frac{V}{td}$$

in which v = maximum shearing unit stress, in pounds per square inch;
V = total shear at section, in pounds;
t = thickness of web of I beam or channel, in inches;
d = depth of I beam or channel, in inches.

For a rectangular section,

$$v=\frac{1.5V}{bd}$$

in which b = width of section and d = depth of section, both in inches.

At any point in a beam there is a horizontal shearing unit stress equal to the vertical shearing unit stress.

Safe Load on Beam.—The safe uniform load on a beam may be found by the following formula:

$$W=\frac{2Sf}{3l}$$

in which W = safe load, in pounds;
S = section modulus of beam;
f = allowable unit stress, in pounds per square inch;
l = span of beam, in feet.

The actual size of a wooden beam differs from its nominal size, and the actual dimensions should be used in calculations.

The dimensions, areas, moments of inertia, and section moduli for timbers are given in the accompanying table.

Example.—What uniform load can be safely carried on a span of 16 ft. by a 6″×10″ beam for which the allowable unit stress is 1,000 lb. per sq. in.?

Solution.—The section modulus for a 6″×10″ beam is 82.7. Hence, the safe load on the beam is

$$W=\frac{2Sf}{3l}=\frac{2\times 82.7\times 1{,}000}{3\times 16}=3{,}450 \text{ lb.}$$

Deflection.—Lack of stiffness in beams causes vibrations, springy floors, excessive deflection or sagging, and cracks in the plaster of ceilings. The maximum deflection of a simple beam carrying a uniform load may be found by the formula

$$D=\frac{5Wl^3}{384EI}$$

in which D = deflection, in inches;
W = uniform load, in pounds;
l = span of beam, in inches;
E = modulus of elasticity of material;
I = moment of inertia of beam.

The deflection of beams supporting plastered ceilings should not exceed $\frac{1}{360}$ times the span.

Example.—What is the deflection of the beam in the preceding example, if the modulus of elasticity of the wood is 1,400,000?

Solution.—Since the moment of inertia of a 6″×10″ beam is 330 and the span in this case is 16×12=192 in., the deflection is

$$D=\frac{5Wl^3}{384EI}=\frac{5\times 3{,}450\times 192^3}{384\times 1{,}400{,}000\times 330}=.69 \text{ in.}$$

Method of Design.—The first step in designing a steel or timber beam is to compute the maximum bending moment and the maximum shear produced by the given loading. Then, the required section modulus is determined by dividing the maximum bending moment by the allowable unit stress. The next step is to find the size of beam with the least cross-sectional area

PROPERTIES OF AMERICAN STANDARD TIMBER SIZES

Nominal Size Inches	American Standard Dressed Size	Area of Section	Moment of Inertia	Section Modulus
2× 4	1⅝× 3⅝	5.89	6.45	3.56
2× 6	1⅝× 5⅝	9.14	24.10	8.57
2× 8	1⅝× 7½	12.19	57.13	15.32
2×10	1⅝× 9½	15.44	116.1	24.44
2×12	1⅝×11½	18.69	205.9	35.82
3× 4	2⅝× 3⅝	9.51	10.4	5.75
3× 6	2⅝× 5⅝	14.76	38.9	13.84
3× 8	2⅝× 7½	19.68	92.3	24.60
3×10	2⅝× 9½	24.93	187.6	39.48
3×12	2⅝×11½	30.18	332.7	57.86
4× 4	3⅝× 3⅝	13.14	14.4	7.94
4× 6	3⅝× 5⅝	20.39	53.8	19.11
4× 8	3⅝× 7½	27.18	127.4	33.98
4×10	3⅝× 9½	34.43	259.0	54.52
4×12	3⅝×11½	41.68	459.4	79.90
6× 6	5½× 5½	30.25	76.3	27.7
6× 8	5½× 7½	41.25	193.4	51.6
6×10	5½× 9½	52.25	330.0	82.7
6×12	5½×11½	63.25	697.1	121.2
6×14	5½×13½	74.25	1,127.7	167.1
8× 8	7½× 7½	56.25	263.7	70.3
8×10	7½× 9½	71.25	535.9	112.8
8×12	7½×11½	86.25	950.6	165.3
8×14	7½×13½	101.25	1,538	227.8
8×16	7½×15½	116.25	2,327	300.3
10×10	9½× 9½	90.25	679	142.9
10×12	9½×11½	109.25	1,204	209.4
10×14	9½×13½	128.25	1,948	288.6
10×16	9½×15½	147.25	2,948	380.4
10×18	9½×17½	166.25	4,243	484.9
10×20	9½×19½	185.25	5,870	602.1

that provides this section modulus and to compute the maximum shearing unit stress for this beam. If this value is less than the allowable shearing unit stress, the beam is satisfactory. Otherwise, a larger beam is tried. The beam that is finally selected is the lightest one that meets the requirements of bending moment and shear and any other conditions that may be important in the particular case. For instance, the depth of the beam may be limited by the construction, or it may be specified that the deflection of the beam should not exceed a certain amount.

Example.—Design both a rolled-steel I beam and a solid wooden beam 10 ft. long, each to carry a uniform load of 250 lb. per ft. in addition to a central load of 2,000 lb., assuming for wood a working stress of 1,000 lb. per sq. in. and for steel 20,000 lb. per sq. in.

Solution.—The maximum bending moment occurs at the middle of the beam and is equal to the sum of the moments due to the uniform load and the central load. Expressed in inch-pounds,

$$M=\frac{2{,}000\times 120}{4}+\frac{250\times 10\times 120}{8}=97{,}500 \text{ in.-lb.}$$

For a steel beam, $\frac{M}{f}=\frac{97{,}500}{20{,}000}=4.9$. From a manufacturer's handbook, a 5-in. I beam at 12.25 lb. has a section modulus of 5.4 and can therefore be used.

For a wooden beam, $\frac{M}{f}=\frac{97{,}500}{1{,}000}=97.5$. An 8″×10″ section, for which the section modulus is 112.8, is satisfactory.

COLUMNS

Slenderness Ratio.—The strength of a compression member depends on the greatest value of the slenderness ratio. In any direction, the slenderness ratio of the member is the ratio of its unsupported length to the radius of gyration. When a member has the same unsupported length in all directions, the least radius of gyration should be used.

A compression member whose unsupported length is less than 10 times its least width is called a short block and is assumed to be subjected only to direct compression. Longer compression members are called columns. A column that carries an axial, or central, load is designed in the same manner as a short block, but the allowable unit stress, which is less than for a short block, is found by a special formula.

Steel Columns.—For steel columns in buildings, the following formulas are commonly used:

When the slenderness ratio $\frac{l}{r}$ is less than 120,

$$f = 17{,}000 - .485\left(\frac{l}{r}\right)^2$$

When the slenderness ratio is greater than 120,

$$f = \frac{18{,}000}{1 + \frac{1}{18{,}000}\left(\frac{l}{r}\right)^2}$$

In designing a column section, the first step is to assume the probable value of f, and to determine the corresponding area by dividing the load by that unit stress. The next step is to proportion the section and to find the allowable unit stress for it by the specified column formula. If this unit stress is slightly greater than the actual unit stress obtained by dividing the load by the area, the section is satisfactory; but, if it is much greater, a section of smaller area should be tried. On the other hand, if the allowable unit stress is less than the actual unit stress, a section of larger area should be assumed and investigated.

EXAMPLE.—A column in a building is to have an unsupported length of 10 ft. and is to carry a central load of 260,000 lb. What is the required size of a single rolled section that will sustain the load?

SOLUTION.—For an assumed unit stress of 15,000 lb. per sq. in., the required cross-sectional area of the column is

$$A = \frac{260{,}000}{15{,}000} = 17.33 \text{ sq. in.}$$

VALUES OF $\left[1-\frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$ FOR TIMBER COLUMNS

$\frac{l}{d}$	K											$\frac{l}{d}$
	21	22	23	24	25	26	27	28	29	30	31	
10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	10
11	.975	.979	.983	.985	.988	.989	.991	.992	.993	.994	.995	11
12	.964	.970	.975	.979	.982	.985	.987	.989	.990	.991	.993	12
13	.951	.959	.966	.971	.976	.979	.982	.985	.987	.988	.990	13
14	.934	.945	.954	.961	.967	.972	.976	.979	.982	.984	.986	14
15	.913	.928	.940	.949	.957	.963	.968	.973	.976	.979	.982	15
16	.888	.907	.922	.934	.944	.952	.959	.964	.969	.973	.976	16
17	.857	.881	.901	.916	.929	.939	.948	.955	.961	.966	.970	17
18	.820	.851	.875	.895	.910	.923	.934	.943	.951	.957	.962	18
19	.776	.815	.845	.869	.889	.905	.918	.929	.939	.946	.953	19
20	.726	.772	.809	.839	.863	.883	.900	.913	.925	.934	.942	20
21	.667	.723	.768	.805	.834	.858	.878	.895	.908	.920	.930	21
22		.667	.721	.765	.800	.829	.853	.873	.890	.904	.915	22
23			.667	.719	.761	.796	.824	.848	.868	.885	.899	23
24				.667	.717	.758	.792	.820	.844	.863	.880	24
25					.667	.715	.755	.788	.816	.839	.859	25
26						.667	.713	.752	.785	.812	.835	26
27							.667	.712	.750	.781	.808	27
28								.667	.710	.747	.778	28
29									.667	.709	.745	29
30										.667	.708	30
31											.667	31

A 12-in.×58 lb. wide-flange section has an area of 17.06 sq. in. and will be tried. The least radius of gyration of that section is 2.51 in. and the slenderness ratio is $\frac{l}{r}=\frac{10\times 12}{2.51}=47.8$. Hence, the safe unit stress is

$$f=17{,}000-.485\left(\frac{l}{r}\right)^2=17{,}000-.485\times 47.8^2=15{,}890 \text{ lb. per sq. in.}$$

This is slightly greater than the actual unit stress, which is

$$\frac{P}{A}=\frac{260{,}000}{17.06}=15{,}240 \text{ lb. per sq. in.}$$

The assumed section is therefore satisfactory.

Timber Columns.—The formula to be used for the safe stress f in a timber column depends on whether the ratio of the unsupported length l to the least width d is greater or less than a number K that is found by the following formula:

$$K=\pi\sqrt{\frac{E}{24f_1}}$$

in which E = modulus of elasticity of material;
f_1 = allowable compressive unit stress for short block of material.

If the ratio of l to d is less than K, the formula for the allowable unit stress f is

$$f=f_1\left[1-\frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$$

If the ratio of l to d is greater than K, the formula is

$$f=\frac{.274E}{\left(\frac{l}{d}\right)^2}$$

In order to facilitate the application of the formula for the allowable unit stress in a timber column for which the ratio $\frac{l}{d}$ is less than K, values of the term $\left[1-\frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$ for various values of K and $\frac{l}{d}$ are given in the table on page 110. Thus, after the value of K has been obtained and the ratio $\frac{l}{d}$ has been determined the corresponding value of the multiplier of f_1 in the formula for f may be taken from the table. The value of $\frac{l}{d}$ for a solid timber column should not exceed 50. To find the allowable unit stress for a timber column with a circular cross-section, it is assumed that the section is a square one having the same area and d is taken as .886 times the diameter.

Example.—Design a square timber column 16 feet long to carry an axial load of 85,000 pounds. The allowable unit stress f_1 is 1,200 lb. sq. in. and K is 23.4.

Solution.—If the allowable unit stress f for the column is assumed to be 1,000 lb. per sq. in., the cross-sectional area of the trial section should be

$$A=\frac{P}{f}=\frac{85{,}000}{1{,}000}=85 \text{ sq. in.}$$

A 10″×10″ section has an area of 90.25 sq. in. and will be tried. For this section, $\frac{l}{d}=\frac{16\times 12}{9.5}=20.2$, and the corresponding value of $\left[1-\frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]$ is found to be .815. Hence, the allowable unit stress is

$$f=f_1\left[1-\frac{1}{3}\left(\frac{l}{Kd}\right)^4\right]=1{,}200\times .815=978 \text{ lb. per sq. in.}$$

Also, the actual unit stress is

$$f=\frac{P}{A}=\frac{85{,}000}{90.25}=942 \text{ lb. per sq. in.}$$

Since the allowable unit stress is not much greater than the actual unit stress, the next smaller section need not be tried, and the 10″×10″ section may be adopted. Ans.

Cast-Iron Columns.—A formula for the safe stress in cast iron columns is

$$f=9{,}000-40\frac{l}{r}$$

ROOF TRUSSES

STRESSES IN MEMBERS

The stresses in the members of a roof truss for any given condition of loading may be found by drawing a frame diagram and a stress diagram. A frame diagram is an outline of the truss, drawn accurately to scale; and a stress diagram is a diagram in which the stresses are represented by lines. A single frame diagram may be used for different conditions of loading, but it is usually necessary to draw at least two stress diagrams, one for dead loads and the other for wind loads, which are generally assumed to act normal to the roof surface. It is not necessary to draw a stress diagram for the snow load, as the snow-load stresses can be obtained from the dead-load stresses by simple proportion.

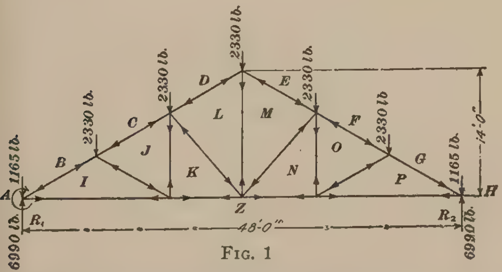


FIG. 1

In order that the frame and stress diagrams may be conveniently compared, the following system of notation is generally employed: As shown in Fig. 1, a capital letter is placed in each of the spaces in the frame diagram that are formed by the truss members and the lines of action of the loads and reactions; and each member or force is designated by the two letters in the spaces between which it lies. Thus, the part of the left-hand rafter near the support of the truss is called member BI, the vertical member at the center is LM; and the left-hand load of 2,330 lb. is BC. As shown in Fig. 2, a small letter is placed at each intersection of lines in the stress diagram; and the stress in each member is represented in the stress diagram by the line between the points having the small letters corresponding to the capital letters used in designating the respective member. Thus, the stress in BI is represented by the line bi, and the stress in JK by the line jk. It is to be understood that, wherever capital letters are used, reference is made to the frame diagram; and, where small letters are used, reference is made to the stress diagram.

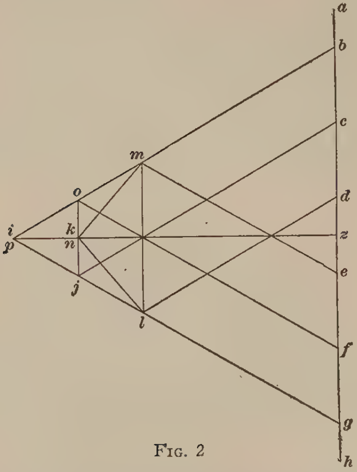


FIG. 2

ANALYSIS OF HOWE ROOF TRUSS

Stress Diagrams for Vertical Loads.—*Dead Load.*—To explain the principles in laying out stress diagrams for roof trusses and determining the amount and kind of stress in any member, stress diagrams will be drawn for a Howe truss and a Fink truss. In Fig. 1 is shown the frame diagram for a Howe truss with dead load only. Since the loads are equal and symmetrically placed, each reaction will be one-half the total load. Letter the frame diagram as shown, and proceed with the stress diagram in Fig. 2. The external forces, which include loads and reactions, having been determined (this should be done in every case), draw the load line *ah* vertically, as that is the direction in which the forces act. With any convenient scale, make *ab*, *bc*, *cd*, etc. equal, respectively, to the forces *AB*, *BC*, *CD*, etc. The reactions *HZ* and *ZA* being equal, *z* is located midway between *h* and *a*. Then the *polygon* of *external forces*, as it is called, is from *a* to *b*, *b* to *c*, *c* to *d*, *d* to *e*, and so on to *h*, and then back from *h* to *z* and from *z* to *a*, the starting point. It will be observed from this that, though a straight line has been drawn, in reality a many-sided polygon has been traced, each external force constituting a side. The internal forces, or the stresses in the truss members, may now be determined, as follows: Beginning at the left-hand joint in the frame diagram, the forces are *BI*, *IZ*, *ZA*, and *AB*. Care must be taken, in reading these forces in the stress diagram, to go around each joint in the same direction in which forces are designated in the frame diagram, namely, in the direction of the movement of the hands of a watch, as shown by the curved arrow around the joint in question in Fig. 1. From *b* draw *bi* parallel to *BI*, and from *z* draw *zi* parallel to *IZ*; their intersection is at *i*, and the polygon of forces around the joint is from *a* to *b*, *b* to *i*, *i* to *z*, and *z* to *a*, the starting point. After having designated all the forces at a joint in the stress diagram, always read around the polygon of forces in the manner just explained, and see that it *closes*, that is, that the last line joins the first, forming a closed figure. Also, note the direction in which the forces travel along each line in the stress diagram, and mark the same by arrowheads upon the members in the frame diagram. Arrowheads acting away from a joint, as in *IZ*, denote tension; those acting toward one, as in *BI*, denote compression. Tensile stresses are usually indicated by a plus sign, and compressive stresses by a minus sign.

The next joint is *BCJI*, and the lines determining the stresses are obtained by drawing, from *c*, *cj* parallel to *CJ*, and, from *i*, *ji* parallel to *JI*; their intersection is at *j*, and the polygon of forces around this joint is from *c* to *j*, *j* to *i*, *i* to *b*, and *b* to *c*, the starting point. In similar manner the stresses around any joint may be obtained.

When the apex joint is reached, the diagram begins to repeat; thus, *em* is the same as *dl*. The stress diagram is, therefore, symmetrical about a central axis and each half serves as a check on the other half.

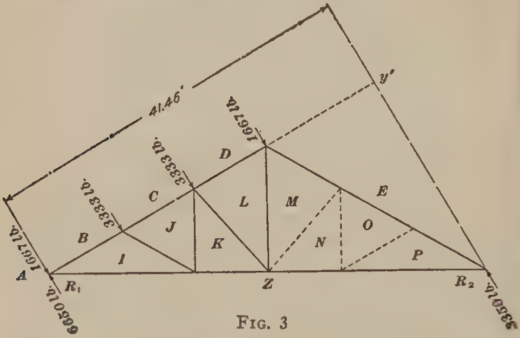


FIG. 3

Snow Load.—It is assumed that the snow load is distributed the same as the dead load. At each panel point it is taken as 2,400 lb. as against 2,330 lb. for the dead load. Therefore, each panel snow load is 2,400 ÷ 2,330 = 1.03 times the dead load, and as the distribution is the same, the stress in each member caused by the snow is 1.03 times the stress caused by the dead load. Therefore, in cases like this there is no necessity to draw a snow-load diagram as the snow-load stress in any member may be computed by multiplying the dead-load stress by 1.03.

Stress Diagram for Wind Load.—It is not necessary to draw a separate frame diagram for the wind loads, but this is done here for clarity. In Fig. 3 are shown the wind loads on the truss previously considered. Both ends of the truss are assumed to be fixed and the reactions are considered to act parallel to the wind pressures. If, however, the left end of the truss is fixed and the right end rests on rollers (as is sometimes the case with steel trusses to permit expansion), the right reaction, instead of being parallel to the direction of the wind, will be vertical.

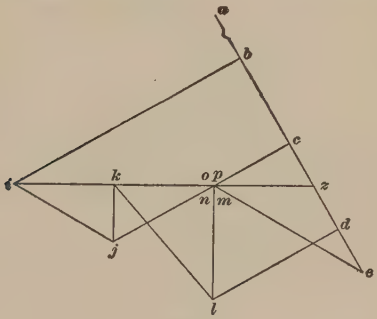


FIG. 4

To determine reactions R_1 and R_2, let R_1 be the center of moments; then the perpendicular distance between the line of action of R_2 and the point R_1 is 41.46 ft., obtained by extending the left-hand rafter to intersect the line of action of R_2 at y'. Regard Ay' as a beam, and calculate reactions R_1 and R_2 by the method given for beams. Taking moments about R_1, the reaction R_2 is found to be 3,350 lb.; and $R_1 = 10,000$ lb. (the total load) $-$ 3,350 lb. $=$ 6,650 lb.

Proceed with the wind-stress diagram, Fig. 4, by drawing the load line *ae* parallel to the direction of the wind in the frame diagram. Lay off to any scale the forces *ab*, *bc*, *cd*, etc. equal to *AB*, *BC*, *CD*, etc., respectively. Then, from *a* lay off *az*, equal to reaction *ZA*, or R_1. If the loads have been laid off accurately, *ez* should be equal to R_2.

The first joint to analyze is *ABIZ*. Draw *bi* parallel to *BI*, and from *z*, *zi* parallel to *IZ*; they intersect at *i*. The polygon of forces is from *a* to *b*, *b* to *i*, *i* to *z*, and *z* to the starting point *a*. Joint *BCJI* is analyzed similarly.

To analyze joint *IJKZ*: *ij* being known, the next member is *JK*; from *j* draw *jk*, parallel to *JK*. As the next member is *KZ*, to which *kz* is parallel, the point *k* is located where *jk* intersects *kz*; this completes this joint, the polygon of forces being from *i* to *j*, *j* to *k*, *k* to *z*, and *z* to *i*. The stresses at the other joints may be found in the same way. The members shown in dotted lines do not sustain wind stresses when the wind blows upon the left side of the truss.

The final joint is *DEML*, at which there is only one unknown force—the stress in *EM*. A line drawn from *e* parallel to *EM* should pass through *m*. This is always a test of the accuracy of the work; and, if the last line does not close on the proper point, when drawn parallel to the member it represents, the stress diagram should be redrawn.

The stresses, which are found by scaling the stress diagrams, are shown in the accompanying tabulation. As the truss is

Member	Dead-Load Stress	Snow-Load Stress	Wind-Load Stress	Maximum Stress
IZ	+10,000	+10,300	+9,900	+25,300
IB	−11,600	−11,900	−8,500	−27,800
CJ	− 9,300	− 9,600	−6,700	−22,300
JI	− 2,300	− 2,400	−3,800	− 7,300
JK	+ 1,200	+ 1,200	+1,900	+ 3,700
KZ	+ 8,000	+ 8,200	+6,600	+19,500
KL	− 3,100	− 3,200	−5,100	− 9,800
DL	− 6,900	− 7,100	−4,800	−16,400
LM	+ 4,700	+ 4,800	+3,900	+11,500
ZP	+10,000	+10,300	+3,300	+22,000
EP	−11,600	−11,900	−5,800	−26,400

symmetrical, only half of the members are included. The maximum stress in any member is either the sum of the dead-load stress, the wind-load stress, and half of the snow-load stress; or the sum of the dead-load stress, the snow-load stress, and half of the wind-load stress.

DEAD-LOAD STRESSES IN FINK TRUSS

In Fig. 5 is shown a frame diagram for a Fink truss with vertical loads. If each intermediate panel load is assumed to be twice the end panel load, the stress diagram is as shown in Fig. 6. To construct this diagram, the load line *aj* is drawn and the point *z* is located midway between *a* and *j*, or midway between *e* and *f*. The joints *ABKZ*, *BCLK*, and *KLMZ* may be analyzed in the manner previously described, and the joints *k*, *l*, and *m* are located. It is then found that there are three unknown forces at each of the joints *CDONML* and *MNQZ*. Since it is not possible to complete the force polygon for a joint at which there are more than two unknown stresses, the value of one must be determined in some other way. In this case, the joint at which the load *DE* is applied is similar to the joint at the load *BC*; and the stress in member *OP* is evidently the same as that in *KL*. Also, the joints *KLMQ* and *NOPQ* are similar, and the stress in member *ON* is equal to that in *LM*. Since the lines *ml* and *no* must be symmetrical

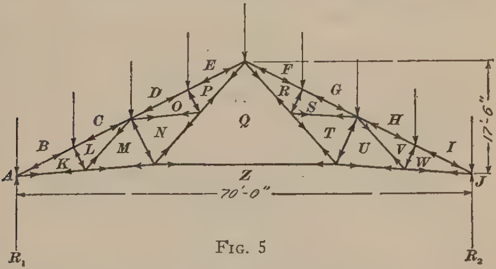


FIG. 5

with respect to the line *mn*, the point *o* may be located by drawing the line *do* parallel to *DO* and placing *o* on the imaginary prolongation of line *kl*. The point *n* can then be located by completing the polygon of forces for the joint *CDONML*; that is, by drawing a line from *m* parallel to *MN* and a line from *o* parallel to *ON*.

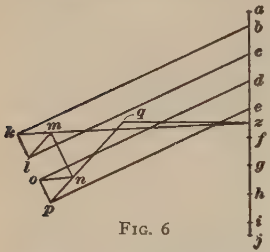


Fig. 6

The joint *MNQZ* now offers no difficulty, as the stress in *MN* is known. The polygon of forces for the final joint *OPQN* may be completed merely by drawing the line from *p* parallel to *PQ*. If the diagram has been correctly drawn, this line will pass through point *n* and coincide with *nq*.

MASONRY CONSTRUCTION

CONCRETE

CEMENTS AND AGGREGATES

Definition of Concrete.—Hydraulic-cement concrete, commonly called concrete, is prepared by mixing a mortar made of hydraulic cement, sand, and water with pieces of broken stone, gravel, slag, or cinders. When freshly mixed, concrete can be poured into molds or forms, and on hardening takes the shape of the mold. The material which is bound together by the cement paste in concrete is called the aggregate. The part of the aggregate which is less than $\frac{1}{4}$-in. in size is called the fine aggregate and usually includes only the sand; the remainder is called the coarse aggregate.

Definition of Cement.—The principal hydraulic cement used in making concrete is portland cement, which may be defined as the product resulting from the process of grinding an intimate mixture of calcareous (containing lime) and argillaceous (containing clay) materials, calcining (heating) the mixture until it starts to fuse, or melt, and grinding the resulting clinker to a fine powder.

Portland cement is packed in cloth or paper sacks. A sack contains 94 lb. of cement, and its volume is usually taken as 1 cu. ft. The unit known as a barrel is equivalent to four sacks.

Aggregates.—The sand for mortar and concrete is usually obtained from natural deposits, and it should be hard, coarse, and clean or free from injurious amounts of clay, loam, and vegetable matter. The coarse aggregate usually consists of gravel or broken stone obtained by crushing rock in a rock crusher or by hand. Trap rocks, granite, hard limestones, and sandstones are satisfactory for crushed stone. Other coarse aggregates that are used in concrete are blast-furnace slag, cinders, and haydite, which is burned clay.

The principal characteristics of aggregates that affect the strength and workability of concrete are soundness, cleanness, and grading. Since the function of aggregate in concrete is that of an inert filler added to the cement paste to reduce the cost of concrete, the type of aggregate has relatively small effect on the strength. Usually the aggregates are stronger than the concretes made from them. A coating of dirt or dust on the particles of aggregate will reduce the strength of concrete, as it prevents proper bond of the mortar with the particles. Well-graded aggregates are essential to the production of economical concrete of good quality. If poorly graded, even clean, sound aggregate will require excessive water for workability, producing low strength, or will require an excessive amount of cement for a given strength.

Water.—The water used in mixing concrete should be clean, fresh, and free from dirt or vegetable matter. Water containing even small quantities of acid may seriously injure the concrete. The presence of oil will result in slow setting and decreased strength.

Salt is sometimes added to the water used in mixing concrete for winter work, because salt lowers the freezing point of water and thereby delays the freezing of concrete. Salt so used is objectionable, because it delays the hardening and decreases the strength, and causes the formation of chemical compounds that crystallize on the surface of the masonry as a whitish deposit called efflorescence. The use of an accelerator, such as calcium chloride, is sometimes advantageous.

PROPORTIONING CONCRETE

Requirements.—The fundamental requirements of proportioning concrete mixtures are: (1) Each particle of fine aggregate must be coated with a film of cement paste and each particle of coarse aggregate must be coated with mortar; (2) all the voids or spaces between the individual grains must be filled; and (3) the cement paste itself must be of the proper quality. Economy dictates that a given quantity of paste be used to bind together a maximum amount of aggregate.

Arbitrary Proportions.—A method of proportioning concrete mixtures that was formerly in common use was to specify the number of cubic feet of sand and coarse aggregate to be mixed with each sack of cement. It was then customary to use half as much sand as coarse aggregate. For ordinary purposes the concrete mix consisted of one sack of cement, assumed to have a volume of 1 cu. ft.; 2 cu. ft. of sand, measured damp and loose as it came from the stock pile; and 4 cu. ft. of coarse aggregate, also measured damp and loose. This was called a 1:2:4 (one, two, four) mix. Mixtures in the proportions 1:1:2, $1:1\frac{1}{2}:3$, $1:2\frac{1}{2}:5$, and 1:3:6 were also used under certain conditions. Concrete mixtures designed on the basis of arbitrary proportions are defective for several important reasons.

Water-Cement Ratio Law.—The amount of mixing water in the cement paste or binding medium governs the properties of concrete to such an extent that the fundamental law of proportioning mixtures may be expressed as follows:

Law.—*For plastic and workable mixes made from clean and sound aggregates under given conditions of manufacture, the strength of concrete is determined by the quantity of mixing water in proportion to the quantity of cement.*

The water-cement ratio is generally expressed in terms of the number of gallons of water per sack of cement. The maximum quantity of mixing water is fixed by the specified strength of the concrete, or by the class of work and degree of exposure.

Design of Mix.—The design of a concrete mixture consists of first selecting the water-cement ratio that corresponds to the desired strength, and then finding the most suitable combination of aggregates which will give the desired workability. Ordinarily, the driest consistency and the coarsest grading that will be workable under the given conditions are desirable, care being taken to avoid mixes that cannot be easily handled, puddled, and finished. Where the concrete must be plastic enough to fill the forms and surround the reinforcing bars with but little tamping or compaction by other means, the volume of sand in the average mix will be about two-thirds of the volume of coarse aggregate. However, if the concrete is compacted in the forms through impulses that are imparted by internal vibrators, satisfactory workability is obtained with less water and a lower proportion of sand; the desired strength can be obtained more economically by using less cement and more coarse aggregate.

After the job is started, tests may be made to determine the effect of job conditions by finding out the strength obtained from two or three water-cement ratios. The points corresponding to the observed strengths and the given water-cement ratios can then be plotted on a diagram, and a curve through these points will represent accurately the strength to be expected from any water-cement ratio used on that job.

Slump Test for Workability.—The water content not only affects the properties of the hardened concrete but also has an important influence on the consistency of the freshly made mixture.

A simple measure of consistency that may be used in the field is the slump. The apparatus for determining the slump is a metal mold having the form of a truncated cone. Its height is 12 in., the top diameter is 4 in., and the bottom diameter is 8 in. The freshly mixed concrete is placed in the mold in three layers, each layer being rodded 25 times with a bulletpointed rod $\frac{5}{8}$ in. in diameter and 24 in. long. When filled, the mold is immediately withdrawn and the slump or settlement of the concrete measured from a straightedge held across the top of the mold. While useful within practical limits for indicating the consistency of concrete, the slump test should not be used to compare mixes of entirely different proportions or various kinds of aggregates.

Desirable Proportions of Fine and Coarse Aggregates. Owing to the wide variety of grading of aggregates used in concrete, no fixed rule of proportioning can be applied to all cases. For each job, and for each set of aggregates available, there is an ideal combination which should be determined according to one of the methods of proportioning that have been proposed by various engineers. The simplest method is by direct trial of the materials in an actual mix.

With a fixed water-cement ratio and a given coarse aggregate, less of a fine sand than of a coarse sand will be required to obtain a specified consistency. More of a given sand will be required (1) when the maximum size of coarse aggregate is reduced; (2) when the particles of coarse aggregate are nearly all of one size; or (3) when the coarse aggregate consists of rough or angular particles rather than smooth, rounded pebbles.

Quantities of Materials for Concrete.—An approximate rule has been devised by W. B. Fuller whereby, after the proportions of aggregates have been fixed, the required quantity of cement per cubic yard of concrete may be obtained. This rule applies to proportions of aggregates measured damp and loose and may be expressed by the formula

$$C = \frac{42}{1+s+g}$$

in which C = sacks of cement per cubic yard of concrete;
s = number of cubic feet of damp loose sand per sack of cement;
g = number of cubic feet of coarse aggregate per sack of cement.

Then the quantities of aggregates can be found by the formulas

$$S = .037Cs$$
$$G = .037Cg$$

in which S = volume of damp loose sand, in cubic yards, per cubic yard of concrete;
G = volume of coarse aggregate, in cubic yards, per cubic yard of concrete.

MANUFACTURE OF CONCRETE

Mixing Concrete.—There are two methods of mixing concrete; namely, *machine mixing* and *hand mixing*. Practically all concrete, even for small jobs, is mixed by machine. Concrete made by either hand or machine should be mixed for a time sufficient to insure the uniform distribution of particles and paste throughout the mass, the elimination of dead spots, and the coating of each particle with paste. A good rule is to continue mixing for one full minute after all materials are in the mixer before anything is withdrawn.

Placing Concrete.—Concrete should be deposited as nearly as possible in its final position, as flowing in the forms tends toward separation of the water and fines from the rest of the mass. Entrained air should be permitted to escape by tamping or puddling the wet concrete in the forms. Spading the concrete next to the forms will make surface finishing easier. If a layer of water is unavoidably formed, it should be drained off. When deposited in the forms, the concrete should have a temperature of not more than 120° F. nor less than 40°, a good average temperature being 60° to 70°.

Curing.—It is desirable to prevent concrete from drying out too quickly. The process of keeping concrete damp and at a favorable temperature for a certain length of time to insure complete hardening is called curing the concrete. The most reliable method of curing concrete appears to be the application of water to exposed surfaces by sprinkling or ponding, or by covering the surface with damp sand, earth, straw, canvas, or other suitable material. This method has the advantage of giving excellent curing conditions at the surface, the most important place.

Exposed surfaces should be protected from drying out for at least 7 da., a longer period being advisable if practicable. Vertical surfaces may be protected by leaving forms on as long as possible, or by hangings of canvas or burlap kept sprinkled.

Summary.—The important principles in the manufacture of concrete are:

The mix should be workable and the water-cement ratio should be low.

The proper water-cement ratio for any job depends on the expected conditions of exposure and requirements of strength, wear, bond, water-tightness, etc.

Other conditions being constant, a lower water-cement ratio may be used with (1) a richer mix, (2) a drier consistency, or (3) a better graded aggregate in which there is a large proportion of coarse particles.

Economy of concrete depends on (1) cost of materials, and (2) cost of placing.

Economy of materials is obtained through leaner mixes. For a given water-cement ratio a leaner mix may be obtained with (1) a drier consistency or (2) a better graded aggregate containing sufficient coarse particles.

Proportioning is a matter of trial to determine the most economical mixture that will be workable under the conditions for the particular job.

Aggregate for concrete should be clean. sound, and durable.

Uniform aggregate supply and uniform moisture conditions greatly simplify the production of uniform concrete.

Water in aggregate must be considered in measuring water for the batch.

Measurements by volume should take account of bulking of aggregate; measurements by weight or by inundation do not involve bulking.

The consistency of concrete is governed by requirements of placing; in general, a medium or quaky consistency is most desirable. Drier consistencies are more economical.

Mixing should be continued as long as practicable, and never less than 1 minute

Means of transportation should insure against segregation of the coarse aggregate from the mortar.

Concrete should be placed in forms as nearly as possible in its final position.

Thorough tamping or spading aids surface finishing and removes air pockets.

Finishing operations should not bring fine material to the surface, causing checking.

Concrete should be protected from drying out for at least 7 da.; the first few hours constitute a critical period for curing concrete surfaces.

The temperature of fresh concrete should never be less than 50° F. nor more than 140°.

Accelerators may be of benefit, but antifreeze compounds are of doubtful value.

Any method of extracting water from fresh concrete without disarranging the particles, will result in increased density and strength.

STONE MASONRY

MATERIALS

Stone.—Masonry may consist of blocks of concrete or stone, bricks, or terra-cotta tiles bound together with mortar,

Granite is the most valuable stone where strength is required. Its colors range from almost white to dark gray; and from light pink to deep red. It can be quarried in very large pieces and is susceptible of a high polish. Owing to its hardness, it is very costly to dress, and its use is limited to the most expensive kinds of buildings. It is very dense and compact, and absorbs but little water. Exposed to fire, it disintegrates at a temperature of from 900° to 1,000° F., being less durable in this respect than fine-grained compact sandstone.

Limestone is a very common building stone. When compact, it is very durable. Its color is generally light gray; sometimes, deep blue; and, occasionally, cream or buff. It is usually quite absorptive and becomes dirty quickly. Under intense heat, it is converted into lime. Limestone must be well seasoned before use, to get rid of the quarry water.

Marble is crystallized limestone. It is comparatively scarce and expensive; hence, it is not often used in constructional work. But it is extensively used in building construction for decorative purposes.

Sandstones, in general, are excellent building stones, and include some of the most durable and beautiful stones used in exterior construction. On account of the ease with which they can be worked and because of their wide distribution throughout the country, they are more extensively used than any other stones. They are capable of resisting great heat, and the better kinds absorb only small quantities of water. A stone containing much iron pyrites is apt to become discolored, due to the formation of rust; hence, the stone should be carefully examined to see that pyrites are not present. Sandstones are found in a great variety of colors, shades of gray, brown, pink, red, drab, and blue being common.

Slate, although not strictly a building stone, is largely used for the roofs of buildings, templates, blackboards, steps, and sanitary purposes. Its valuable qualities are its strength, toughness, and non-absorptive character, as well as its tendency to split into sheets.

Selecting Stones for Masonry.—The densest and strongest stones are generally the most durable. A fresh fracture, when examined under a magnifying glass, should be clear and bright, showing well-cemented particles. When a good stone is tapped with a hammer, it gives out a ringing sound. The absorptive quality of a stone may be tested by noting the increase in weight after soaking in water for 24 hr. One that increases 5% or more should not be used. For ordinary building purposes, tests of crushing strength are unnecessary, for if stone is of good quality the strength is generally very much in excess of any probable loads.

Cement Mortar.—Cement mortar consists of cement, sand, and water. Portland cement should be used for all important structures, but natural cement may occasionally be employed where conditions permit. As for concrete, the sand should be hard, clean, of suitable size, and properly graded; and the water should be clean and fresh.

MATERIALS REQUIRED PER CUBIC YARD OF MORTAR

Proportions of Mixture	Portland Cement Sacks	Loose Sand Cubic Yards
1:1	18.6	.7
1:2	12.2	1.0
1:3	9.1	1.1
1:4	7.2	1.1
1:5	6.1	1.2
1:6	4.9	1.2

Portland cement mortars are made in proportions varying from 1:1 to 1:6. For general purposes, the mortar should be of a plastic consistency—firm enough to stand at a considerable angle, yet soft enough to work easily. In the preceding table are given average quantities of cement and sand required to produce 1 cubic yard of compacted mortar.

It is frequently desired to use a material that is more plastic or smoother than pure cement mortar. This quality is usually obtained by adding to the mortar an amount of lime equal to 10 to 25% of the weight of the cement.

A good method of mixing cement mortar is as follows: After one-half the quantity of sand is spread over the bottom of the mortar box, spread the cement evenly over the sand, and then put on the remainder of the sand. Thoroughly mix the dry materials either by hoe or by shovel; then add water to as much of the mass as is required for immediate use, and mix this portion until it has the uniform consistency of a stiff paste.

The quantity of water required depends on the purpose for which the mortar is to be used. Owing to the rapidity of setting, only small lots of this mortar should be mixed at a time.

Some stones are stained by ordinary portland cement mortar. Such stones should be laid in a mortar composed of non-staining, or stainless, portland cement and white sand.

Lime Mortar.—Quicklime is made by burning limestones, that have the requisite properties, in kilns. When properly burned, quicklime should possess the following qualities: It should be in hard lumps, free from cinders or clinkers, and should slake readily in water forming a smooth, impalpable paste, without residue.

Before quicklime is used, it must be slaked by adding water to it. The lumps break up and a thick paste, called lime paste, is obtained. This paste is allowed to stand for a week or 10 days before it is used. Slaked lime may be kept indefinitely if it is protected from the elements by a covering of sand.

Hydrated lime is quicklime that has been thoroughly slaked by the aid of machinery. It may be used in place of common lime. It is in the form of a fine dry powder, to which water is added to make a paste. Hydrated lime is commonly sold in 50-lb. bags or sacks.

In mixing lime mortar, a bed of sand is first made in a mortar box, and the lime is distributed as evenly as possible over it. The lime is slaked by pouring on water and covering with a layer of sand or, preferably, a tarpaulin, to retain the vapor given off. Sufficient water should be used at the start; if more is added later, it chills the hot lime and makes it lumpy. Too much water makes the paste thin, weak, and slow in drying. Additional sand is then added, if necessary, until the mortar contains the proper proportion, which is usually 3 of sand to 1 of lime. The bulk of the mortar will be about one-eighth greater than that of the dry sand alone.

Useful Data on Cement Mortar.—The following is a summary of the important points concerning cement mortar:

1. The strength of a mortar depends primarily on the percentage of cement in the mixture, and on the volume of mixing water per sack of cement.

2. The most economical mortar for a specified strength is obtained by using a well-graded sand and the driest mixture that will be workable.

3. The best sand is, in general, that which will produce the smallest volume of mortar when mixed with the cement in the required proportions.

4. Sharpness of sand grains is of slight importance.

5. Coarse sand produces stronger mortar than fine sand.

6. Fine sand requires more water than coarse sand to produce a mortar of like consistency, and consequently its mortar is less dense.

7. Mixtures of fine and coarse sand, or of sand and screenings, often produce better mortar than either material alone.

8. Impurities in sand, such as vegetable loam, even in minute quantities, may injure the strength of the mortar.

9. The average weight of portland-cement mortar in proportions $1{:}2\frac{1}{2}$ is 135 lb. per cubic foot.

Masonry Cements.—There are prepared cements, known as masonry cements, that are used in making mortar for laying stone, brick, terra-cotta, tile, and concrete-block masonry. Some of these cements are sold under the trade names of *Brixment*, *Carney's Cement*, *Hy-Test*, *Kosmortar*, *Medusa Stoneset*, and *Medusa Brikset.*

Masonry cements are formed of natural rock that contains suitable combinations of clay and lime. Most of these cements contain also a waterproofing ingredient such as calcium stearate. These materials are mixed in varying proportions by different manufacturers. They are sold in cloth or paper sacks, each sack containing 1 cu. ft. of the material. The contents of a sack are mixed with 3 cu. ft. of sand and with sufficient water to form a workable mortar.

Mortars made from masonry cements are plastic and work well under the trowel; also, they adhere firmly to the surfaces to which they are applied. The cements are mixed uniformly at the factory and, when the proper amounts of sand and water are added according to the directions of the manufacturer, a mortar of uniform quality should be obtained. The addition of the waterproofing ingredient tends to keep the wall dry and to prevent the absorption of water by the mortar after it is dry. This quality assists in preventing the appearance of efflorescence on the face of the wall.

The time required for the mortar to set is regulated by the original mixture. Some of the mortars may be retempered without loss of strength, whereas others must be used soon after being mixed with water.

The quantities of mortar, cement, and sand required for a brick wall will vary according to the thickness of the joints and the thickness of the wall, as well as the completeness with which the joints are filled with mortar.

CLASSES OF STONE MASONRY

Rubble Masonry.—Rubble masonry is used for rough work, such as foundations, backing, etc. Although it frequently consists of common field stone, quarried stone should be used where possible, as better bonding and bedding can be secured.

In Fig. 1 (*a*) is shown a common- or random-coursed rubble wall, in which the stones are bonded every 3 or 4 ft., as at *a*. The angles are laid with large well-shaped stones, the long sides alternating; in the body of the wall, the stones are set irregularly, the interstices in the heart of the wall being filled with spalls and mortar.

In (*b*) is shown cobweb rubble. The quoins, or corner stones, are hammer-dressed on top and bottom, but may be rock-faced. All the joints should be hammer-dressed and no spalls should show on the face, while the joints should not be thicker than ½ in. Cobweb rubble costs more than common rubble.

In (*c*) is shown a rubble wall with brick quoins; in this work all the horizontal joints have hammer-dressed level beds. Such a wall can be built cheaply when the stone used splits readily.

In (*d*) is shown regular-coursed rubble; in this work continuous horizontal joints are run at intervals of 15 to 18 in. in the height, as at *abc* and *def*. No attention need be paid to uniformity of height in the different courses, but the beds should be made as nearly parallel as possible.

Rubble masonry varies in strength with the shape and character of the stone. If the stone has a marked stratification and splits up into flat layers, a very strong wall can be built with it. Rubble walls require a large amount of mortar, but mortar may be saved if spalls or chips of stones are bedded in the mortar between the larger stones. The stones should be of such a size that they can be handled by two men.

A through stone, or bond stone, should be built in the wall for every 6 square feet of wall surface; or stones, two-thirds the thickness of the wall, may extend from the opposite faces

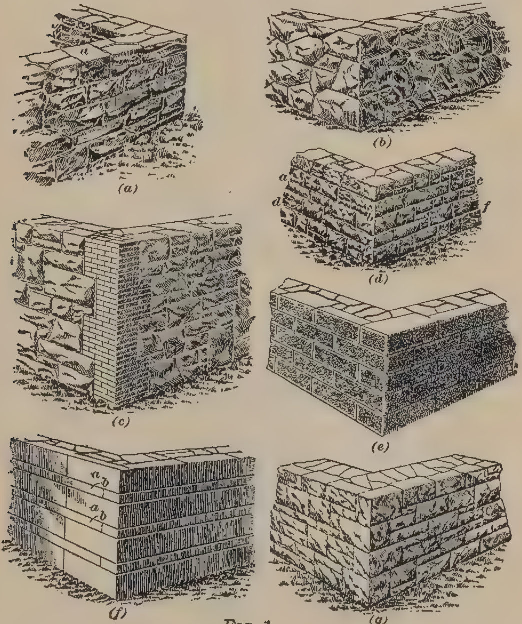


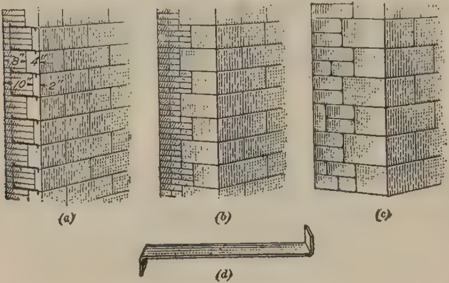
FIG. 1

of the wall and overlap each other once in every 4 square feet of wall surface.

Ashlar.—When the outside facing of a wall is of cut stone with the joints carefully cut and squared, it is called ashlar regardless of the manner in which the face of the stone is finished.

Regular-coursed ashlar, shown in Fig. 1 (*e*), has pieces uniform in height and the courses continuous. Stones about 12 in. high and from 18 to 24 in. long are the cheapest, both as to first cost and in expense of handling. The illustration shows the stone bush-hammered with tooled draft lines. A good effect is produced by making the courses of two different heights, as shown in (*f*), the courses *a* being from 10 to 18 in. high and composed of facers, while the courses *b* are from 5 to 7½ in. high and constitute bonding courses. The latter should be at least 4 in. wider than the thickest stones used in the facing courses.

Broken ashlar consists of blocks truly squared but of different sizes, forming a broken range or course. As this masonry is in itself irregular, it is well adapted to buildings of irregular plan or of irregular sky line. Broken ashlar is finished in various ways. The simplest, though not the least effective, finish is the plain rock face, shown in (*g*). The block must first be cut true and square all around, forming beds and vertical joints, after which straight lines are drawn around the edges, about 2 in. from the face of the block. A wide pitching chisel is then used along these lines, knocking off the



(*a*) (*b*) (*c*)

(*d*)

FIG. 2

surplus material. The smallest stone used should not be less than 4 in. in height, nor the largest greater than 16 in. The bond, or the lap of one stone over another, should be at least 6 in. for the smaller stones and 8 in. for the larger. The length of any block should not be less than 1½, nor more than 4, times its height. The hardest kinds of rock are best suited for masonry of this sort, which is, perhaps, the most common kind of ashlar used in modern building.

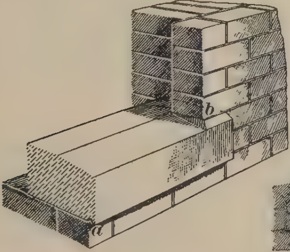


FIG. 3

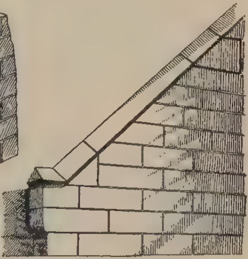


FIG. 4

Ashlar should be carefully bonded, either by using courses of different thicknesses, or, if the ashlar is only 2 to 4 in. thick, by means of anchors, such as shown in Fig. 2 (*a*) and (*d*). When the courses are 4 in. to 8 in. thick, a good bond to the backing may be had by using these thicknesses in alternate courses, as in (*b*) and (*c*).

The stones in ashlar with brick backing should be designed to be a certain number of brick courses in height so that it will bond well, as in (*b*). Ashlar should be set in a mortar made with a non-staining cement or a white portland cement. The backs of the stones are frequently coated with a non-staining portland cement mortar.

All projecting courses, such as cornices, lintels, sills, etc., should be beveled on top, and have a drip, such as shown at *a*, Fig. 3, cut on the under side to prevent water from entering the joints. Lug sills should be beveled only between the jamb lines, the ends being cut level, as at *b*, thus keeping out water from the joint between brick and stone, and also forming a more secure bearing for the wall.

The tops of exposed walls should be covered by coping. Gable copings should be anchored very firmly, either by iron dowels or ties, or by bond stones, the latter method being shown in Fig. 4.

When the wall is finished, the mason starts at the top of the building and points all the joints, and cleans the stonework. During the progress of the work all projecting members such as cornices, belt-courses, and sills should be protected, by boarding, from injury that might be caused by falling pieces of building material.

STONE FINISHES

Some of the hand tools used in making the finer finishes for stonework are shown in Fig. 5. The crandall (*a*) consists of a wrought-iron bar, flattened at one end, with a slot, $\frac{3}{8}$ in. wide and 3 in. long, in which ten double-headed points, made of $\frac{1}{4}$ in. square steel about 9 in. long, are fastened by means of a key. It is used to finish the surface of sandstone after it has been worked with the tooth-axe or chisel.

The patent hammer (*b*), made of several thin blades of steel, ground to an edge and held together with bolts, is used for finishing granite or hard limestone.

The bush hammer (*c*), from 4 to 8 in. long and 2 to 4 in. square, has its ends cut in pyramidal points. This hammer is used for finishing limestone and sandstone after the surface has been made nearly even.

In practice, hand tools are used only on small pieces of work. In most cases, similar tools that are operated by compressed air can do the work more rapidly and more cheaply.

In (*d*) is shown the appearance of rock-faced or pitch-faced work. The face of the stone is left rough, just as it comes from the quarry, and the edges are pitched off to a line. Rock-faced finish is cheaper than any other kind, as but little work is required.

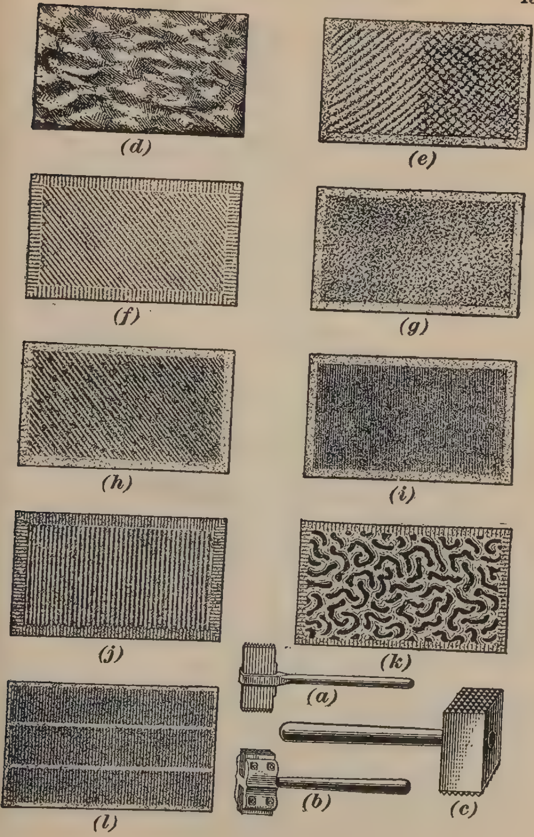


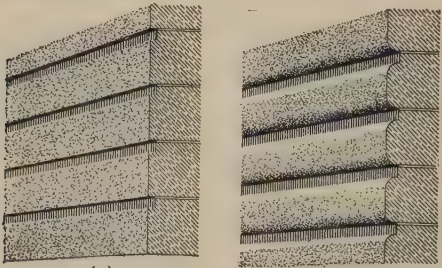
FIG. 5

In (*e*) are shown two kinds of crandalled work; that on the left shows the appearance when the lines run all one way, while that on the right shows the lines crossing.

In (*f*) is shown broachea work, in which continuous grooves are formed over the surface.

In (*g*) is shown bush-hammered work, which leaves the surface full of points. This finish is very attractive on bluestone, limestone, and sandstones, but should not be used on very soft stones.

In (*h*) is shown pointed work; the left half of the stone is rough-pointed, while the right half is fine-pointed. In the rough-pointed work, the point is used at intervals of 1 in. over the stone, while, in the fine-pointed, the point is used at every ½-in. of the surface.



(*a*) (*b*)

FIG. 6

In (*i*) is shown the patent-hammered finish, generally used on granite, bluestone, and limestone. The stone is first dressed to a fairly smooth surface with the point, and then finished with the patent hammer. The fineness of the work is determined by the number of blades in the hammer. For U. S. government work, 10 cuts per in. are generally specified, but 8 cuts per in. is good work.

In (*j*) is illustrated tooled work. For this finish, a chisel from 3 to 4½ in. wide is used, and the lines are continued across the width of the stone to the draft lines.

In (*k*) is shown vermiculated work, so called from the worm-eaten appearance. Stones so cut are used in quoins and base courses. This dressing is very effective, but expensive.

In (*l*) is shown droved work, similar to tooled work, except that the lines are broken, owing to the smaller size of the chisel used. It is less expensive than tooled work.

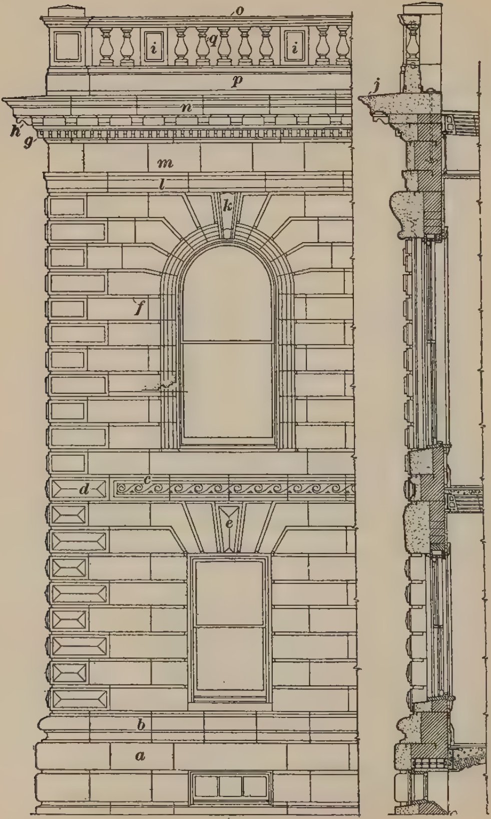
When a smooth finish is desired, the surface of the stone is rubbed. This is best done before the stone becomes seasoned.

The term rusticated work is generally used to designate sunken or beveled joints. Two examples of this finish are shown in Fig. 6 (*a*) and (*b*). View (*a*) shows the stones with recesses having sharp edges, and (*b*) with recesses having rounded edges. The joints should always be formed at the top of the rustication so that they may be protected from rain water, which would tend to work its way into the joints if they were at the bottom of the rustication.

ASHLAR FRONT

In the accompanying figure is shown part of an elevation of a building finished with ashlar. The ashlar is treated with rusticated joints throughout. In the basement walls, the stones are finished with a curved rustication *a*, which gives a massive effect suitable for this part of the building. The rustication shown in the upper part of the façade has square edges, which is lighter in effect than that shown on the basement. The basement wall is finished by a water-table *b*, which is heavily molded. At *c* is shown a belt-course, or string-course, which indicates approximately the level of the floor. This string-course is ornamented with a carved ornament, called a wave ornament, and is kept with a slight projection so that it will not extend beyond the quoin *d*. The quoins, or corner stones, are shown with wedge-shaped ornaments in the first story and in the second story with raised rectangular surfaces. In practice, the quoins are treated the same throughout the design.

The sill of the basement window is a regular stone sill with a wash, or slope, on the upper surface and with lugs on the ends. A slip sill or sill that is fitted in between the jambs or sides of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the opening, is shown for the first-story window. The basement window has a straight stone lintel above it; this is shown backed up with brickwork that is supported on steel beams.

Over the first-story window is a flat arch of stone. In order that the soffit, or under surface of the arch, may not appear to be depressed or sag in the middle, it is generally cambered, or built with a slight curve that is higher in the middle. The keystone *e* is ornamented the same as the quoin *d*.

The second-story window has a semicircular arch over it, and the rustications are brought down to the window opening. A molded stone trim or architrave is set in this opening, giving the window a rich effect. The horizontal line through the center of the arch is kept above the nearest horizontal joint *f*. which makes the arch appear slightly stilted and consequently more effective. The keystone *k* is emphasized by a bracket or console.

The entablature, consisting of an architrave *l*, frieze *m*, and cornice *n*, is about one-fifth of the distance between the top of the water-table and the bottom of the architrave. The cornice is of the Corinthian type and contains dentils *g* and modillions *h*. The cornice should be covered with a flashing of lead or copper, which will protect the upper surface from the effects of water and prevent the washing out of the joints. This flashing is let into a reglet, or groove, *j* as near the front edge of the cornice as possible.

The balustrade above the cornice is shown with a high base *p*; otherwise, it would be cut off from view by the projecting cornice. The base of the balustrade should be flashed by letting the flashing into grooves cut into the stone. The balusters *q* are turned and separated into groups by blocks *i*. The top rail *o* and the bottom rail should be cut with washes, and the balusters should be doweled into both rails with metal dowels.

The stones are anchored to the backing as shown, and the upper stones of the cornice should be anchored down to the wall by bolts, which extend into the joints between the stones. Washers are fitted to both ends of these bolts.

NOTES ON STONEWORK

Stone being the stronger material, a wall should have as much stone and as little mortar as possible. The thickness of joints in stonework is from $\frac{3}{16}$ to $\frac{1}{2}$ or $\frac{5}{8}$ in., depending on the class of work; the usual thickness is about $\frac{1}{4}$ in. for ordinary ashlar, and more in rough masonry. Bed joints should be full and square to the face, for if worked slack at the back—to make thin face joints—spalls are likely to break off at the front edges. Good bonding is essential for a strong wall, and the proper placing of headers should be carefully watched. Long pieces of stone should be well supported and bedded to prevent breaking; pieces longer than, say, four times the thickness should not be used. Stone, especially if stratified, should be laid on its natural or quarry bed, for, if set vertically, water easily penetrates between the layers, and, in freezing, splits off the outer ones. In laying stone, the mortar should be kept back about 1 in. from the face of the wall; otherwise, spalls may be broken off, owing to the outside mortar hardening more rapidly than that in the interior, settlement bringing the pressure on the hard layer. This precaution is very important in the case of lug sills, band courses, etc. The joints may be pointed, after the wall is built, with some non-staining mortar. When the temperature has reached the freezing point, it is unsafe to dress-cut unseasoned stone in the open air, as the quarry sap in the stone freezes, and the stone may be fractured during the process of cutting.

If it is desirable to use grout, which usually is ordinary mortar thinned to the consistency of cream, stone or brick should not be wetted before being laid. They will then absorb water from the grout and also some of the cement, and the adhesion will thus be increased.

BRICK MASONRY

Kinds of Brick.—Bricks are made in many varieties, such as common brick, face brick, firebrick, paving brick, molded brick, hollow brick, glazed brick, enameled brick, etc.

Common bricks should be thoroughly burned, hard, straight, true, and uniform in size. If two bricks are struck together, they should give out a ringing sound; if the sound is dull, the bricks are of an inferior quality. The color should be red, and bricks that are too light, or salmon-colored, are apt to prove too soft for use. A brick should not absorb more than 10% of its weight of water. The standard size of common bricks may be given as $2\frac{1}{4}'' \times 3\frac{3}{4}'' \times 8''$, but the size varies in different localities.

Face bricks are made in a variety of colors, textures, sizes, and shapes. The term face brick generally refers to bricks that have been pressed into a mold by machinery before burning; are carefully shaped with square corners, smooth surfaces, and sharp edges; and are of uniform size. Some face bricks have rough surfaces. Face bricks are generally burned hard and absorb very little water.

Firebricks are used where great heat is to be resisted, as in fireplaces, furnaces, flues, etc. They should be porous, so as to be poor conductors of heat. The size is about $9'' \times 4\frac{1}{4}'' \times 2\frac{1}{2}''$ and the weight about 7 lb. per brick. They are of a light cream color and are laid up with a mortar made of fireclay like that of which they are made.

Paving bricks are made by burning a mixture of shale and fireclay to vitrification. They should have a crushing strength of about 8,000 lb. per sq. in. and should absorb very little water. They are used for paving driveways and roads.

Molded bricks are pressed bricks made in special ornamental forms, and are used in building up cornices, belt-courses, arches, etc.

Enameled bricks and glazed bricks are used for the interiors of kitchens, bath-rooms, and swimming pools, and wherever a hard sanitary surface is desired. The usual size is $2\frac{1}{4}'' \times 3\frac{7}{8}'' \times 8''$.

Bond.—Brickwork lends itself to some very interesting and artistic effects, which are produced by various methods of bonding, or arranging the brick in the face of the wall, and also by varying the size and colors of the mortar joints and using bricks of different colors and textures. The following are some of the common terms used in connection with bonding: A course is one horizontal row of brick laid in mortar. A stretcher is a brick showing its long side in the face of the wall. A header is a brick showing the end in the face of the wall. A bat is a portion of a brick and is used sometimes as a header.

In Fig. 1 are shown the three principal bonds in brickwork. In (*a*) is shown English bond, consisting of alternate courses of stretchers and headers. The longitudinal bond may be obtained by means of one-quarter bats, as shown, though preferably by three-quarter bats. In (*b*) is shown Flemish bond, consisting of alternate headers and stretchers in the same course. The lap is obtained by use of three-quarter bats, with quarter, half, and three-quarter interior closers. In (*c*) is

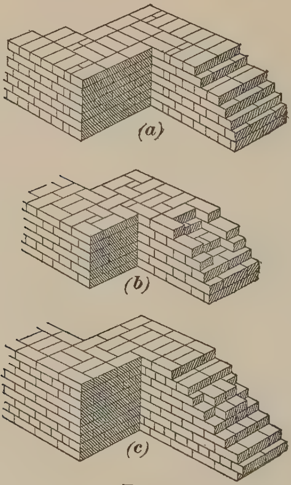

FIG. 1

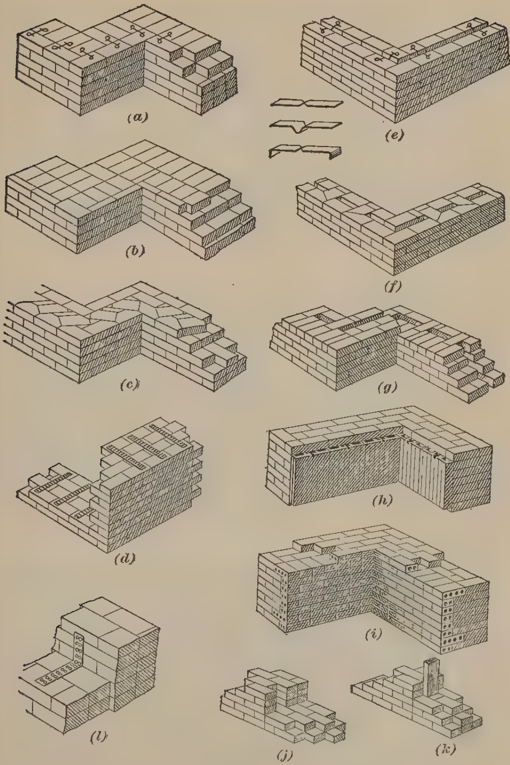

FIG. 2

shown the ordinary bond known sometimes as garden, running, or American bond. It consists of five or six courses of stretchers to each course of headers.

From (*a*) to (*g*) in Fig. 2 are shown methods of bonding face brick to the backing in both solid and hollow walls. In (*h*) is shown split furring tile, which is set in mortar against the brick walls and anchored to the walls by large nails. In (*i*), the brick wall is lined with hollow brick, which are bonded into the wall and take the place of furring and lathing. In (*j*), (*k*), and (*l*) are shown methods of joining old and new walls; (*j*) shows a vertical groove cut in the old wall to form a sliding joint with the new wall; (*k*), a 2″×4″ piece spiked to the old wall for the same purpose; and (*l*), a steel-tie bond fastened to the walls with nails (also adapted for bonding face brick).

A great variety of effects can be obtained by the judicious use of the various bonds in laying face brick. Three arrangements are shown in Fig. 3.

Joints.—The treatment of the joints can be made a very effective feature in face-brick work. The joints may be raked out, as shown in the central arrangement in Fig. 3, and are often made as wide as 1 in.; they may be made of mortar containing gravel or grit, and made wide and cut off flush with the face of the wall, as in the top arrangement; or they may be made fine and finished with great care as in the bottom arrangement.

Laying Brick.—Where the wall is built entirely of common brick, the joints are from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. thick. When the wall is faced with face brick, stone, or terra cotta, the brick wall is referred to as the backing. The distance apart of the horizontal joints of facing material must be designed so as to coincide with the joints of the backing every few courses, to permit of a good bond. A face-stone or terra-cotta course is designed to be, say, five or six courses of common brick in height, so that the iron anchor that holds the stone or terra cotta to the backing can be extended back into the wall. When face brick is used and the distance from center to center of joint is different from that of the backing, the joints should be

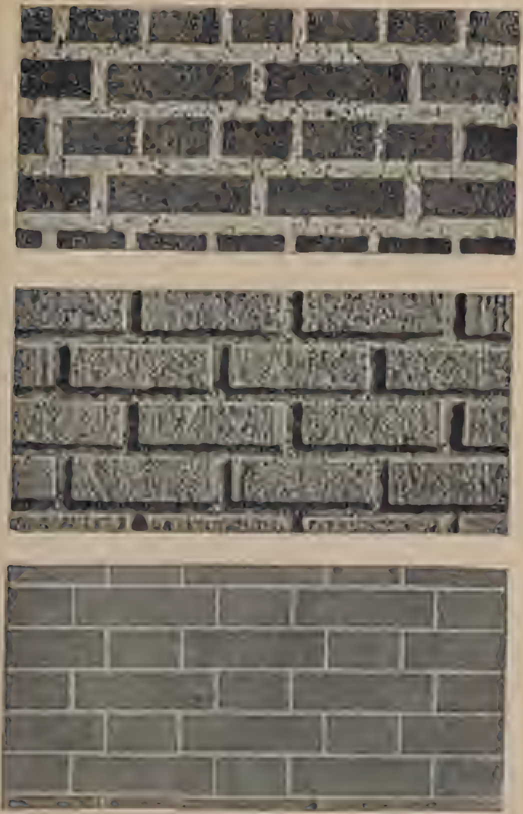

Fig. 3

made to coincide every five or six courses so as to permit of good bonding.

In laying up a wall, skilled workmen are put on the corners of the building and start the wall plumb and with the proper bond and thickness of joint. A line is then stretched between these corners for every course and the intermediate wall is laid up to the line. The face brick is sometimes carried up to the next bond course before the backing is laid. Sometimes one gang of masons will lay up the face work, while another gang will build the backing at the same time.

Bricks should be laid in a full bed of mortar and shoved into place so that the mortar will fill all the joints. The spaces in the middle of the wall should be entirely filled with mortar. When the weather is hot, the bricks should be thoroughly wet before they are laid in the wall so that they will not absorb the water from the mortar. In freezing weather, the materials may be warmed.

The walls should be covered over with boards or tarpaulins when the workmen are through for the day to protect the work from rain and cold weather, and to prevent injury by frost.

PORTLAND-CEMENT MORTAR MATERIALS REQUIRED TO LAY 1,000 BRICKS

Size of Joint Inches	Mortar Cubic Feet	Cement Sacks	Sand Cubic Feet	Hydrated Lime Cubic Feet
$\frac{3}{16}$	8	2.67	8	.67
$\frac{1}{4}$	10	3.33	10	.83
$\frac{5}{16}$	12	4.00	12	1.00
$\frac{3}{8}$	15	5.00	15	1.25
$\frac{1}{2}$	18	6.00	18	1.50
$\frac{5}{8}$	22	7.33	22	1.83
$\frac{3}{4}$	26	8.67	26	2.17

Mortar.—For thick rough joints, the mortar should be mixed with grit or small pebbles and a small quantity of hydrated lime. If a white color is desired, white cement with white sand or marble dust should be used in making the mortar. A gray color is obtained by using dark-colored portland cement and brown sand. Mortar may be colored by using mineral pigments, but care must be taken to follow an exact formula in mixing the ingredients, or the different batches of mortar may be differently colored, and the wall may look blotchy. When mortar dries out, it usually becomes lighter in color.

In the accompanying table is given the amount of 1:3 portland-cement mortar required to lay 1,000 bricks. It also includes the number of sacks of cement, cubic feet of sand, and cubic feet of hydrated lime mixed in the proportion of 10% of the weight of the cement.

A similar table for 1:3 masonry-cement mortar in a 12-in. wall follows.

MASONRY-CEMENT MORTAR MATERIALS REQUIRED TO LAY 1,000 BRICKS

Size of Joint Inches	Mortar Cubic Feet	Cement Sacks	Sand Cubic Feet
1/4	9.7	3.1	9.3
3/8	12.9	4.1	12.3
1/2	16.2	5.1	15.3

ARCHITECTURAL TERRA COTTA

Architectural terra cotta is a burned clay product that is used for trimming or covering exterior or interior walls or partitions of buildings; or for forming facings, cornices, columns, sills, lintels, string courses, etc. It is a decorative material principally, and adds little or nothing to the strength and stability of the building.

Architectural terra cotta is made from selected clays, which, after preparation and tempering, are formed into the desired architectural forms by being pressed into molds. Usually the molds are made of plaster from full-size models. When, however, only one piece is required, the clay may be modeled directly to the required design by the hand of the sculptor, Also, special treatment can be given to the blocks after they come from the molds. The blocks are next carefully dried, placed in kilns, and burned at temperatures from 1,800° to 2,300° F. for about 12 da.

Usually architectural terra cotta is manufactured to meet the special architectural requirements of each building, with attention to design, color, texture, etc. Some manufacturers, however, carry in stock certain patterns of wall blocks, string courses, sills, lintels, panels, and the like, which may be shipped on short notice. These blocks are made to bond with standard brickwork, as a rule.

The manufacturer furnishes estimates for furnishing, and sometimes setting, the terra cotta, based on the architect's drawings and specifications. These drawings should include elevations, floor plans, and sections, as well as the steel drawings and details, if available. If concealed behind porches, railings, and insides of entrances, the location and dimensions of the terra cotta surfaces should be clearly indicated. Special mention should be made of such terra cotta interior work as may not be readily discernible from the drawings.

Architectural terra cotta may be obtained in a number of surface textures, as follows: smooth; tooled, or drove, 6 or 8 lines to the inch; light irregular drag, or combing; heavy irregular drag, or combing; special, as rugged, oak bark, etc. The color may be standard, which is that of light Indiana limestone, or unglazed; or, by means of surface coatings, any desired color or colors may be obtained. The color is usually applied as a glaze. Thus, the surface may be standard, or unglazed; vitreous, which is impervious to moisture; mat-glazed or mat-enameled, which is glazed and has a dull finish that is impervious; and full-glazed, or enameled, which is impervious and has a glossy finish. Polychrome terra cotta may be in two or more colors, unglazed or glazed. Blended colors are always glazed. The colors, textures, and finishes should be stated explicitly, and fully described in the specifications. The colors, textures, and finishes appear on the exposed surfaces only.

Architectural terra cotta is made into box-like blocks, the thickness of the outside shell varying from 1 to 2 in., depending on the size and shape of the block. The back may be open, exposing the webs, or the back may be closed. When used as slabs, the blocks may be solid, and about 2 in. thick.

When built in the wall, architectural terra cotta weighs from 120 to 130 lb. per cu. ft. The price of the terra-cotta work depends on the variety of design and other conditions. Economy of manufacture, however, is greatly assisted by the repetition of identical features in the same building, as a smaller number of molds will be required.

As there is some variation in shrinkage in burning, it is customary to grind all the blocks to exact size, with allowance for a standard joint of $\frac{3}{16}$ or $\frac{1}{4}$ in. The terra-cotta manufacturer will always supply a setting diagram, numbered to correspond with numbers marked on the blocks, and this diagram must be followed exactly in setting the material.

The part of the terra-cotta block extending into the wall should be backed up with brick, or filled with concrete, so that the strength of the wall will be uniform throughout. When solid-back blocks are used, the blocks are set the same as cut stone. In cases where the terra cotta is supported on or by structural steel, the manufacturer will provide slots for the steel and will furnish such schedules or drawings as are required to show the method of support. All the blocks must be properly tied into the brickwork or supported by the steel work, as may be shown on the setting diagram. The blocks should extend into the wall at least 4 in., except when used as a veneer in the form of slabs. When the block extends out from the face of the wall, as in a cornice, the backing stops at the wall line.

The time required to manufacture architectural terra cotta varies according to the character of the work; 8 wk. is ordinarily considered the minimum time for the first shipment of plain work after receipt of the working drawings approved by the architect. Manufacturers of terra cotta claim for their material unlimited possibilities in the matter of form; a surface finish that is impervious; unlimited scope in color effects;

lightness of weight combined with great tensile strength; fire-resisting qualities that are testified by the kiln heat in burning; and the durability that is characteristic of all well-burned clay products.

HOLLOW TILE CONSTRUCTION

Types of Hollow-Tile Units.—Hollow tile, or structural clay tile, considered as a manufactured material, consists of blocks, or units, formed of clay and burned. The blocks have shells and webs surrounding hollows or cells in the interior of the units. These units are used in the same manner as stone, brick, or other units.

The units, or blocks, themselves, are known as hollow tile or structural clay tile, and are made in sizes that permit of the construction of walls 8 in., 12 in., etc., in thickness. The tiles are also used as backing for walls faced with brick or stone. Other hollow-tile units are used for the construction of partitions in buildings, and for furring outside walls. Special shapes are also made for sills, jambs, lintels, etc.

Hollow tile is also used in the construction of floors and for the fireproofing of buildings having steel frames.

Some of the usual shapes and sizes of hollow-tile units are shown in Fig. 1. In (*a*) are standard wall tiles; in (*b*) is a form known as Speedtile, in which a hand-hold is formed in the unit to facilitate handling of the tile; in (*c*) are partition tiles; in (*d*) are flat-arch tiles; in (*e*) are header and jamb tiles; and in (*f*) are split furring tiles.

Hollow clay tiles are made in two principal grades, namely, load-bearing and non-load-bearing. Load-bearing tiles are designed to support loads, as in walls, floors, and roofs. There are two classes of load-bearing tiles. The first class is designed for use in outside walls, where the tiles are subject to severe weathering. Tiles of this class are marked LBX. The other class is suitable for work that is not exposed to the weather, as for interior walls and the backing of veneered walls. These tiles are marked LB. Tiles intended for interior partitions or for other parts that are not expected to support loads are marked NB.

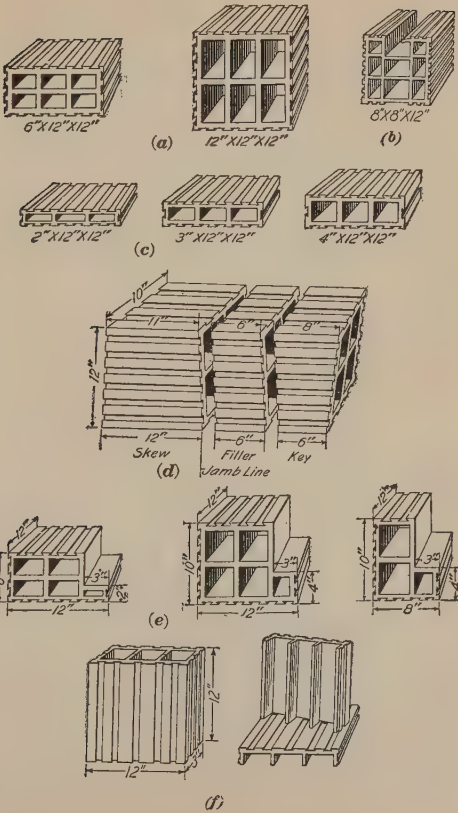
6"X12"X12"
(a)
12"X12"X12"
8"X8"X12"
(b)
2"X12"X12"
3"X12"X12"
4"X12"X12"
(c)
10"
11"
6"
8"
12"
12"
Skew
6"
Filler
6"
Key
(d)
Jamb Line
12"
6"
3"
2"
12"
12"
10"
3"
4"
12"
12"
10"
3"
4"
8"
(e)
12"
12"
3"
(f)

Fig. 1

The surfaces of the tiles may be either smooth or scored to form grooves, which aid in holding mortar, plaster, or stucco. The exposed surfaces may be glazed or enameled, in which case no plaster or stucco is applied to the surface.

Laying Hollow Tile.—Hollow-tile units or blocks are laid up with broken joints so as to form a bond, and are generally set with the cells or air spaces in a vertical position. They may, however, be laid with the cells horizontal. The mortar used consists of 1 part of portland cement to 3 parts of sand. Hydrated lime or well-slacked lime paste to the amount of 10% of the volume of the cement may be added to make the mortar work more smoothly. To prevent water from working through the wall, the mortar beds should not extend in an unbroken layer through the outside walls. Partitions and interior work should be laid with full joints.

REINFORCED CONCRETE*

IMPORTANT PROPERTIES

Reinforcement.—Reinforced concrete is a combination of concrete and steel in which the two materials are so arranged that each will effectively resist the kind of stress it can most economically sustain. In members subjected to both tension and compression, such as slabs and beams, the concrete is allowed to resist compressive stress, and small quantities of steel in the form of rods or wires are introduced to carry the tensile stress and, sometimes, part of the compressive stress. In members subjected to compression, such as columns, the steel resists some of the stress and also strengthens the column against lateral failure. In order that the two materials may act together in resisting stress, the concrete must adhere to the surface of the embedded steel.

In the accompanying table are given the areas and perimeters of the round and square bars that are used in reinforced-concrete construction. As recommended by the United States Bureau of Standards, the sizes of round bars should be limited to $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, and 1 in., and those of square bars to $\frac{1}{2}$, 1, $1\frac{1}{8}$, and $1\frac{1}{4}$ in. The areas and perimeters of the eleven standard sizes are shown in blackface type. The rods may be either plain or deformed.

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*The recommendations of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete are followed here.

AREAS AND PERIMETERS OF ROUND AND SQUARE BARS

Size of Bar Inches	Round		Square	
	Area Square Inches	Perimeter Inches	Area Square Inches	Perimeter Inches
$\frac{1}{4}$	**.049**	**.785**	.063	1.00
$\frac{5}{16}$	.077	.982	.098	1.25
$\frac{3}{8}$	**.110**	**1.178**	.141	1.50
$\frac{7}{16}$	.150	1.374	.191	1.75
$\frac{1}{2}$	**.196**	**1.571**	**.250**	**2.00**
$\frac{5}{8}$	**.307**	**1.964**	.391	2.50
$\frac{3}{4}$	**.442**	**2.356**	.563	3.00
$\frac{7}{8}$	**.601**	**2.749**	.766	3.50
1	**.785**	**3.142**	**1.000**	**4.00**
$1\frac{1}{8}$	.994	3.534	**1.266**	**4.50**
$1\frac{1}{4}$	1.227	3.927	**1.563**	**5.00**

Weight.—The weight of reinforced concrete is usually assumed as 150 lb. per cubic foot. For approximate computations, it is convenient to assume the weight to be 144 lb. per cubic foot, because the weight per linear foot of a member is then equal to the area of its cross-section in square inches.

Protection of Reinforcement.—In fire-resistive construction, the thickness of concrete protection outside the reinforcement should be not less than 1 in. in slabs and walls, and not less than 2 in. in beams, girders, and columns. In structures where the fire hazard is limited, the metal reinforcement should be protected by not less than $\frac{3}{4}$ in. of concrete in slabs and walls and not less than $1\frac{1}{2}$ in. in beams, girders, and columns.

In structures that are subject to moisture, such as footings for walls and columns, the concrete covering for the reinforcement should be not less than 3 in. In structures that are exposed to the weather, the reinforcement should be protected by not less than 2 in. of concrete.

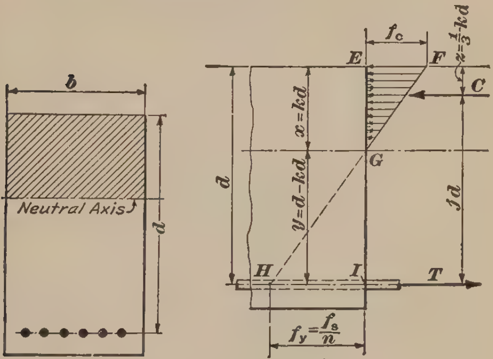
Ratio of Moduli of Elasticity.—In the design of reinforced-concrete members the ratio n of the modulus of elasticity of steel to that of concrete should be assigned values according to the ultimate compressive strength f'_c of the concrete at 28 da., as follows:

f'_c	n
2,000 to 2,400	15
2,500 to 2,900	12
3,000 to 3,900	10
4,000 to 4,900	8
over 5,000	6

REINFORCED-CONCRETE BEAMS

RECTANGULAR BEAMS AND SLABS

General Formulas for Flexure.—A cross-section of a rectangular reinforced-concrete beam is shown in Fig. 1 (*a*), and the distribution of the stresses, as commonly assumed, is shown in (*b*). The compressive stresses vary uniformly from a maximum stress f_c at the top to zero at the neutral axis, as represented by the shaded triangle *EFG*. Between the neutral axis and the steel reinforcement, no tensile stresses are supposed to exist, the assumption being that all tensile stress is resisted by the steel, but the triangle *GHI* represents the variation of the imaginary stresses in the concrete below the neutral axis if the concrete could resist such stresses. The resultant of the compressive stresses is located at the center of gravity of the triangle *EFG*, and it may be assumed that the total compressive stress C is concentrated at that point. The unit stress f_s in the steel is n times as large as the unit stress f_y in a fiber of concrete located at the same distance from the neutral axis, or $f_s = nf_y$. The total tensile stress T acts at the center of gravity of the steel area. The ratio of the area of steel to that of concrete that produces a section in which the full working stresses are developed simultaneously in both materials is known as the balanced steel ratio.



(a) (b)

FIG. 1

Let b = width of beam, in inches;

d = effective depth in inches = distance of steel from top of beam;

$x=kd$ = distance, in inches, of neutral axis from top of beam;

jd = arm of stress couple, in inches = distance between center of steel and resultant compressive stress;

A_s = total area of steel, in square inches;

p = steel ratio $= \frac{A_s}{bd}$;

p_b = balanced steel ratio;

M = bending moment, in inch-pounds;

f_s and f_c = unit stresses in steel and concrete, respectively, in pounds per square inch;

M_s and M_c = moments of resistance of steel and concrete, respectively, in inch-pounds;

r = stress ratio $= f_s : f_c$;
n = ratio of moduli of elasticity of steel and concrete;
K = coefficient for balanced steel ratio;
f'_c = ultimate compressive strength of concrete at 28 days, in pounds per square inch.

Then,

$$k = \sqrt{(pn)^2 + 2pn} - pn$$

$$k = \frac{n}{r+n}$$

$$j = 1 - \frac{k}{3}$$

$$M_c = \tfrac{1}{2} f_c kjbd^2$$

$$M_s = f_s A_s jd$$

$$M_s = f_s pjbd^2$$

$$p_e = \frac{k}{2r}$$

$$p_e = \frac{n}{2r(r+n)}$$

$$M = Kbd^2$$

In the accompanying tables are given values of k, j, p_e, and K for various values of f_s, f_c, and n; and values of k and j for various values of p and n.

The allowable compressive unit stress in the extreme fibers of a reinforced-concrete beam, due to bending moment, should not exceed $.45f'_c$. The working stress for steel reinforcement is generally taken as 18,000 lb. per square inch for bars of the structural steel grade, and 20,000 lb. per square inch for those of the intermediate and hard grades.

EXAMPLE.—Determine (*a*) the width and (*b*) the area of tensile reinforcement of a beam that is to have a total depth of 25 in. and is to resist a bending moment of 927,000 in.-lb. The allowable unit stresses are $f_c = 900$ and $f_s = 18{,}000$ lb. per square inch, $n = 12$, and $p = .01$.

SOLUTION.—(*a*) The first step is to compute the balanced steel ratio in order that the given ratio may be compared with it.

In this case, $r = \frac{18,000}{900} = 20$, and

$$p_e = \frac{n}{2r(r+n)} = \frac{12}{2 \times 20 \times (20+12)} = .0094$$

Since the given ratio, $p = .01$, exceeds the balanced ratio, $p_e = .0094$, the resisting moment of the concrete governs the design. Then

$$k = \sqrt{(pn)^2 + 2pn} - pn = \sqrt{(.01 \times 12)^2 + 2 \times .01 \times 12} - .01 \times 12 = .384$$

Also, $$j = 1 - \frac{k}{3} = 1 - \frac{.384}{3} = .872$$

Therefore, $$bd^2 = \frac{2M}{f_c kj} = \frac{2 \times 927,000}{900 \times .384 \times .872} = 6,150$$

The specified total depth of the beam is 25 in., and, if 2 in. is allowed for protection, $d = 23$ in. Hence, $b = \frac{6,150}{23^2} = 11.6$, say 12 in.

(*b*) Since $p = .01$, the computed value of b is 11.6, and $d = 23$,

$$A_s = pbd = .01 \times 11.6 \times 23 = 2.67 \text{ sq. in.}$$

If $\frac{7}{8}$-in. round rods are assumed, the number required is $\frac{2.67}{.601} = 4.4$, say 5, the total area of which is 3.01 sq. in. A more economic steel area can be provided by means of two 1-in. and two $\frac{7}{8}$-in. round rods, the total area being $2 \times .785 + 2 \times .601 = 2.77$ sq. in.

Formulas for Shear and Bond.—Let

V = total shear at section, in pounds;
v = shearing unit stress, in pounds per square inch;
u = unit bond stress, in pounds per square inch;
O = sum of perimeters of reinforcing bars at section, in inches.

Then $$v = \frac{V}{bjd}$$

and $$u = \frac{V}{jdO}$$

COEFFICIENTS FOR DESIGN OF RECTANGULAR BEAMS AND SLABS

f_s	$n=15$					$n=12$				
	f_c	k	j	p_e	K	f_c	k	j	p_e	K
14,000	500	.349	.884	.0062	77.1	650	.358	.881	.0083	102.5
	550	371	.876	.0073	89.4	700	.375	.875	.0094	114.8
	600	391	.870	.0084	102.1	750	.391	.870	.0105	127.6
	650	.411	.863	.0095	115.3	800	.407	.864	.0116	140.7
	700	.429	.857	.0107	128.6	850	.421	.860	.0128	153.9
	750	.446	.851	.0119	142.3	900	.435	.855	.0140	167.4
	800	.462	.846	.0132	156.3	1,000	.462	.846	.0165	195.4
	850	.477	.841	.0145	170.5	1,100	.486	.838	.0191	224.0
	900	.491	.836	.0158	184.7	1,200	.507	.831	.0217	252.8
16,000	500	.319	.894	.0050	71.3	650	.328	.891	.0067	95.0
	550	.340	.887	.0058	82.9	700	.344	.885	.0075	106.6
	600	.360	.880	.0068	95.0	750	.360	.880	.0084	118.8
	650	.379	.874	.0077	107.7	800	.375	.875	.0094	131.3
	700	.396	.868	.0087	120.3	850	.389	.870	.0103	143.8
	750	.413	.862	.0097	133.5	900	.403	.866	.0113	157.0
	800	.429	.857	.0107	147.1	1,000	.429	.857	.0134	183.8
	850	.443	.852	.0118	160.4	1,100	.453	.849	.0156	211.5
	900	.458	.847	.0129	174.6	1,200	.474	.842	.0178	239.5
18,000	500	.294	.902	.0041	66.3	650	.302	.899	.0055	88.2
	550	.314	.895	.0048	77.3	700	.318	.894	.0062	99.5
	600	.333	.889	.0056	88.8	750	.333	.889	.0069	111.0
	650	.351	.883	.0063	100.7	800	.348	.884	.0077	123.0
	700	.368	.877	.0072	113.0	850	.362	.879	.0085	135.2
	750	.385	.872	.0080	125.9	900	.375	.875	.0094	147.7
	800	.400	.867	.0089	138.7	1,000	.400	.867	.0111	173.3
	850	.415	.862	.0098	152.0	1,100	.423	.859	.0129	199.8
	900	.429	.857	.0107	165.4	1,200	.444	.852	.0148	227.0
20,000	500	.273	.909	.0034	62.0	650	.281	.906	.0046	82.7
	550	.292	.903	.0040	72.5	700	.296	.901	.0052	93.3
	600	.310	.897	.0047	83.4	750	.310	.897	.0058	104.3
	650	.328	.891	.0053	95.0	800	.324	.892	.0065	115.6
	700	.344	.885	.0060	106.6	850	.338	.887	.0072	127.4
	750	.360	.880	.0068	118.8	900	.351	.883	.0079	139.5
	800	.375	.875	.0075	131.2	1,000	.375	.875	.0094	164.1
	850	.389	.870	.0083	143.8	1,100	.397	.868	.0109	189.5
	900	.403	.866	.0091	157.0	1,200	.419	.860	.0126	216.2

VALUES OF k AND j FOR DIFFERENT VALUES OF p

p	$n=15$		$n=12$		p	$n=15$		$n=12$	
	k	j	k	j		k	j	k	j
.0002	.075	.975	.067	.978	.0102	.421	.860	.387	.871
.0004	.104	.965	.093	.969	.0104	.424	.859	.390	.870
.0006	.126	.958	.113	.962	.0106	.427	.858	.393	.869
.0008	.143	.952	.129	.957	.0108	.430	.857	.396	.868
.0010	.159	.947	.143	.952	.0110	.433	.856	.399	.867
.0012	.173	.942	.156	.948	.0112	.436	.855	.401	.866
.0014	.185	.938	.167	.944	.0114	.438	.854	.404	.865
.0016	.196	.935	.178	.941	.0116	.441	.853	.407	.864
.0018	.207	.931	.187	.938	.0118	.444	.852	.409	.864
.0020	.217	.928	.196	.935	.0120	.446	.851	.412	.863
.0022	.226	.925	.205	.932	.0122	.449	.850	.414	.862
.0024	.235	.922	.213	.929	.0124	.452	.849	.417	.861
.0026	.243	.919	.221	.926	.0126	.454	.849	.419	.860
.0028	.251	.916	.228	.924	.0128	.457	.848	.422	.859
.0030	.258	.914	.235	.922	.0130	.459	.847	.424	.859
.0032	.266	.911	.241	.920	.0132	.462	.846	.426	.858
.0034	.272	.909	.248	.917	.0134	.464	.845	.429	.857
.0036	.279	.907	.254	.915	.0136	.467	.844	.431	.856
.0038	.285	.905	.260	.913	.0138	.469	.844	.433	.856
.0040	.292	.903	.266	.911	.0140	.471	.843	.436	.855
.0042	.298	.901	.271	.910	.0142	.474	.842	.438	.854
.0044	.303	.899	.276	.908	.0144	.476	.841	.440	.853
.0046	.309	.897	.282	.906	.0146	.478	.841	.442	.853
.0048	.314	.895	.287	.904	.0148	.480	.840	.444	.852
.0050	.320	.893	.292	.903	.0150	.483	.839	.446	.851
.0052	.325	.892	.296	.901	.0152	.485	.838	.449	.850
.0054	.330	.890	.301	.900	.0154	.487	.838	.451	.850
.0056	.334	.889	.306	.898	.0156	.489	.837	.453	.849
.0058	.339	.887	.310	.897	.0158	.491	.836	.455	.848
.0060	.344	.885	.314	.895	.0160	.493	.836	.457	.848
.0062	.348	.884	.319	.894	.0162	.495	.835	.459	.847
.0064	.353	.882	.323	.892	.0164	.497	.834	.461	.846
.0066	.357	.881	.327	.891	.0166	.499	.834	.463	.846
.0068	.361	.880	.331	.890	.0168	.501	.833	.465	.845
.0070	.365	.878	.334	.889	.0170	.503	.832	.467	.844
.0072	.369	.877	.338	.887	.0172	.505	.832	.468	.844
.0074	.373	.876	.342	.886	.0174	.507	.831	.470	.843
.0076	.377	.874	.346	.885	.0176	.509	.830	.472	.843
.0078	.381	.873	.349	.884	.0178	.511	.830	.474	.842
.0080	.384	.872	.353	.882	.0180	.513	.829	.476	.841
.0082	.388	.871	.356	.881	.0182	.515	.828	.478	.841
.0084	.392	.869	.359	.880	.0184	.517	.828	.480	.840
.0086	.395	.868	.363	.879	.0186	.518	.827	.481	.840
.0088	.399	.867	.366	.878	.0188	.520	.827	.483	.839
.0090	.402	.866	.369	.877	.0190	.522	.826	.485	.838
.0092	.405	.865	.372	.876	.0192	.524	.825	.487	.838
.0094	.408	.864	.375	.875	.0194	.526	.825	.488	.837
.0096	.412	.863	.378	.874	.0196	.527	.824	.490	.837
.0098	.415	.862	.381	.873	.0198	.529	.824	.492	.836
.0100	.418	.861	.384	.872	.0200	.531	.823	.493	.336

The maximum shearing unit stress in the concrete of beams which are not provided with web reinforcement should not exceed $.02f'_c$ for beams with longitudinal reinforcement that is provided with ordinary anchorage at the ends, and $.03f'_c$ for beams in which the longitudinal reinforcement is specially anchored at the ends.

When the shearing unit stress in the beam exceeds the allowable value that is safely resisted by the concrete, web reinforcement should be provided to resist the remaining stress. However, even then, the maximum shearing unit stress in the section should not exceed $.06f'_c$ for beams in which the longitudinal reinforcement is provided with ordinary anchorage and $.12f'_c$ where special anchorage is used. Where the shearing unit stress exceeds $.06f'_c$, the web reinforcement should be designed to resist the entire shear.

For plain bars that are not specially anchored at the ends, the allowable unit bond stress is $.04f'_c$ and for deformed bars it is $.05f'_c$. When the reinforcement is provided with special anchorage, the bond stress may be $1\frac{1}{2}$ times the value for ordinary anchorage.

Web Reinforcement.—Web reinforcement is provided by one of the following methods:

1. Vertical or inclined stirrups;
2. Bent-up tension bars;
3. Combinations of bent-up bars and stirrups.

This reinforcement should be well anchored in the tensile and compressive regions of the beam.

Let s = spacing of web reinforcement, measured parallel to axis of beam, in inches;

f_v = allowable tensile unit stress in web reinforcement, in pounds per square inch;

A_v = area of web reinforcement at section in question, in square inches;

v = shearing unit stress at section, in pounds per square inch;

v_c = allowable shearing unit stress in concrete, in pounds per square inch;

b = width of beam, in inches.

Then, for vertical stirrups,

$$s=\frac{f_vA_v}{(v-v_c)b}$$

For bars inclined 45°,

$$s=\frac{f_vA_v}{.7(v-v_c)b}$$

For bars inclined to the horizontal at any angle X,

$$s=\frac{f_vA_v(\sin X+\cos X)}{(v-v_c)b}$$

For all grades of steel, f_v is taken as 16,000 lb. The value $v-v_c$ to be used in these formulas should be the average shearing unit stress that is resisted by the web reinforcement. When the shearing unit stress is not greater than $.06f'_c$, the distance s between two successive web members, or from the point at which a bar is bent up to the edge of the support, should not be greater than $\frac{d}{2}$ for vertical stirrups or $\frac{3}{4}d$ for bars inclined at an angle, where d is the effective depth of the beam. When the shearing unit stress exceeds $.06f'_c$, the distance s should not be greater than half of these values.

Let x_c = distance from end of span to point where web reinforcement is no longer needed, in inches;
l = length of span, in inches.

Then, for a beam that is uniformly loaded,

$$x_c=\frac{l}{2}\left(\frac{v-v_c}{v}\right)$$

A method of providing vertical stirrups that is somewhat approximate but is good enough for a beam carrying a uniform load is as follows: The minimum spacing s, determined by the formula $s=\frac{f_vA_v}{(v-v_c)b}$, is used at the face of the support, and the spacing is increased to $\frac{4}{3}s$ at a distance of about $\frac{1}{4}x_c$ from the end of the span, to $2s$ at $\frac{1}{2}x_c$, and to $4s$ at $\frac{3}{4}x_c$, provided it does not exceed the maximum allowable value. However, the number of stirrups should not be less than

$$N_v=\frac{\frac{1}{2}(v-v_c)x_cb}{f_vA_v}$$

DOUBLE-REINFORCED BEAMS

When the dimensions of the section of a beam are limited by building conditions, it may be desirable to place steel in the top of the beam, as in Fig. 2, to aid the concrete in resisting the compressive stresses. The beam is then said to be double-reinforced. Let M represent the maximum bending moment that is to be resisted by the beam; M_e the bending moment that the section could resist if it were reinforced at the bottom only with the balanced amount of steel $A_e = p_e bd$; A'_s the area of compressive reinforcement in the top of the beam; A_y the additional tensile reinforcement in the bottom to resist the additional stresses caused by the bending moment $M - M_e$; A_s the total area of tensile reinforcement which is equal to $A_e + A_y$; d' the distance from the top of the beam to the compressive reinforcement; f_x the unit stress in the concrete at that point; f'_s the unit stress in the compressive steel; and I the moment of inertia of the section, the steel being replaced by narrow strips of concrete whose areas are sufficient to produce the same effects in resisting bending moments as the corresponding steel areas. Then, for a given beam, x is found from the relation

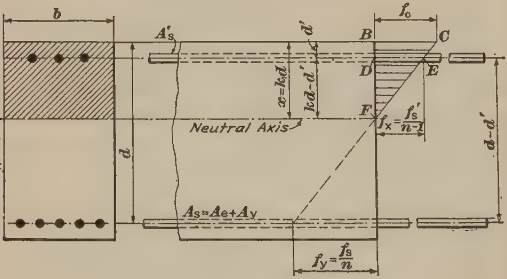


FIG. 2

$$\tfrac{1}{2}bx^2 + (n-1)A'_s(x-d') = nA_s(d-x)$$

Also, $I = \frac{1}{3}bx^3 + (n-1)A'_s(x-d')^2 + nA_s(d-x)^2$

$$f_c = \frac{Mx}{I}$$

$$f'_s = \frac{nM(x-d')}{I}$$

$$f_s = \frac{nM(d-x)}{I}$$

To design a double-reinforced beam, the following formulas are applied:

$$f_x = \frac{f_c(kd-d')}{kd}$$

$$A'_s = \frac{M-M_c}{(n-1)f_x(d-d')}$$

$$A_y = \frac{M-M_c}{f_s(d-d')}$$

T BEAMS

Width of Flange.—If the slabs are poured monolithically with the supporting beams and are tied to them by means of stirrups and rods, part of the slab may be considered effective in helping to resist the compressive stresses in the beam, and the two form a **T** beam, as represented by the shaded area *acdefghi* in Fig. 3. The slab *acdi* constitutes the flange, and the beam below it the stem or web. However, the entire rectangular beam, or *jkfg* in the illustration, is frequently called the stem.

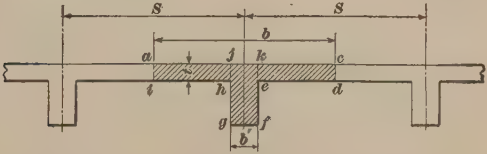


FIG. 3

In the case of symmetrical T beams, the assumed effective flange width should not exceed one-fourth of the span length of the beam, and its overhanging width on either side of the stem should be not more than eight times the thickness of the slab nor one-half the clear distance to the next beam. Therefore, if l is the span of the beam, b' is the width of the stem, t is the thickness of the flange, and S is the spacing center to center of beams, the width b of the flange must not exceed $\frac{l}{4}$, $b'+16t$, or S.

For beams that have a flange on one side only, the effective flange width should not exceed one-tenth of the span length of the beam, and its overhanging width from the face of the stem should be not more than six times the thickness of the slab nor one-half the clear distance to the next beam.

In the case of isolated beams that are built of T-shaped section, the thickness of the flange should be not less than one-half the width of the stem, and the total width of the flange should be not more than four times the width of the stem.

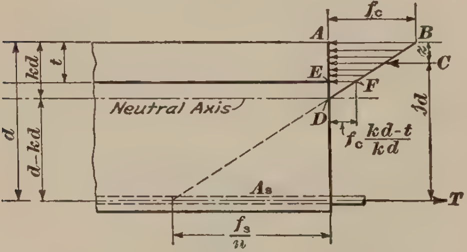


FIG. 4

Formulas for T Beams.—When the neutral axis of a T beam is in the flange, the beam is designed as a rectangular beam whose width is equal to the width of the flange of the T beam. But when the neutral axis is below the flange, as in Fig. 4, the following special formulas apply:

$$kd=\frac{ndA_s+\frac{1}{2}bt^2}{nA_s+bt}$$

$$z=\left(\frac{3kd-2t}{2kd-t}\right)\frac{t}{3}$$

$$jd=d-z$$

$$M_c=\left(\frac{2kd-t}{2kd}\right)f_cbtjd$$

$$M_s=f_sA_sjd$$

$$v=\frac{V}{b'jd}$$

$$u=\frac{V}{jdO}$$

In designing T beams, the following approximate formulas are found useful:

$$b'd=\frac{V}{.875v} \qquad \textbf{Approx.}$$

$$A_s=\frac{M}{f_s(d-\frac{1}{2}t)} \qquad \textbf{Approx.}$$

REINFORCED-CONCRETE COLUMNS

Types of Columns.—Concrete columns may be reinforced by longitudinal bars and lateral ties at intervals of about 8 in. or by longitudinal bars and closely spaced spiral hooping surrounding the bars.

When the unsupported length of a reinforced-concrete column is equal to, or less than, ten times the least lateral dimension of the effective area, the column is considered to be a short column. It is assumed that, when a short column supports an axial load, the load is uniformly distributed over its effective area. If the unsupported length of the column exceeds ten times the least lateral dimension, the column is treated as a long column and an allowance for buckling is made.

Spiral Columns.—The maximum allowable axial load on a short column reinforced with longitudinal bars and spiral hooping that encloses a circular core may be found by the formula

$$P = .225\, f_c' A_g + A_s f_s$$

in which P = allowable axial load, in pounds;

f_c' = 28-day compressive strength of concrete, in pounds per square inch;

A_g = gross area of column, in square inches;

A_s = effective cross-sectional area of longitudinal reinforcement, in square inches;

f_s = nominal working unit stress in longitudinal reinforcement, in pounds per square inch.

The longitudinal reinforcement should consist of at least six bars with a diameter of not less than $\frac{5}{8}$ in., and the effective cross-sectional area of that reinforcement should be not less than 1% and not more than 8% of the gross area of the column section. The unit stress f_s may be taken as 40% of the minimum yield point stipulated in the specifications. It is 16,000 for billet steel of intermediate grade and 20,000 for billet steel of hard grade or for rail steel. The distance along the spiral between the centers of adjacent longitudinal bars should be not less than $2\frac{1}{2}$ times the bar diameter for round bars and not less than 3 times the side dimension of the bars for square bars.

The ratio of the volume of the spiral reinforcement to the volume of the core, or the part of the column within the outside of the spiral hooping, may be found by the formula

$$p' = .45\left(\frac{A_g}{A_c} - 1\right)\frac{f'_c}{f'_s}$$

in which p' = ratio of volume of spiral reinforcement to volume of core;

A_c = cross-sectional area of core;

f'_s = unit stress in spiral reinforcement at useful limit, in pounds per square inch.

The stress f'_s may be taken as 40,000 for hot-rolled rods of intermediate-grade billet steel, 50,000 for rods of hard-grade steel, and 60,000 for cold-drawn wire. The distance between the centers of adjacent hoops of the spiral should not exceed one-sixth of the core diameter, and the clear spacing between hoops should be not more than 3 in. nor less than $1\frac{3}{8}$ in. or $1\frac{1}{2}$ times the maximum size of the coarse aggregate to be used. Also, the spiral reinforcement should be covered by at least $1\frac{1}{2}$ in. of concrete.

EXAMPLE.—A short spiral column of circular section is to carry an axial load of 330,000 lb. If the ultimate compressive strength of the concrete is 2,500 lb. per sq. in., the longitudinal and spiral reinforcement are of hard-grade billet steel, and the minimum amount of reinforcement is used, what should be (*a*) the diameter of the column, (*b*) the longitudinal reinforcement, and (*c*) the spacing of spiral hooping that is $\frac{3}{8}$ in. in diameter?

SOLUTION.—(*a*) In this case, $P = 330{,}000$ lb., $f_c' = 2{,}500$ lb. per sq. in., A_s is taken as $.01\ A_g$, and $f_s = 20{,}000$ lb. per sq. in. When these values are substituted in the formula for P, the result is

$$330{,}000 = .225 \times 2{,}500\ A_g + .01\ A_g \times 20{,}000$$

and the required gross area of the column is

$$A_g = \frac{330{,}000}{.225 \times 2{,}500 + .01 \times 20{,}000} = 433 \text{ sq. in.}$$

The corresponding diameter is $\sqrt{\dfrac{433}{.785}} = 23.5$, say 24 in. Ans.

(*b*) The area of longitudinal reinforcement should be $.01 \times .785 \times 24^2 = 4.52$ sq. in., which can be supplied by eight $\frac{7}{8}$-in. round bars. Ans.

(*c*) If $1\frac{1}{2}$ in. of concrete is provided outside the spiral, the diameter of the column core is $24 - 2 \times 1\frac{1}{2} = 21$ in. and the core area is $.785 \times 21^2 = 346$ sq. in. Since $f'_s = 50{,}000$ lb. per sq. in., the ratio of the volume of spiral reinforcement to the volume of concrete is

$$p' = .45\left(\frac{A_g}{A_c} - 1\right)\frac{f'_c}{f'_s} = .45 \times \left(\frac{452}{346} - 1\right) \times \frac{2{,}500}{50{,}000} = .0069$$

In an inch of height of column, the volume of spiral reinforcement should be $.0069 \times 346 = 2.39$ cu. in. Since the cross-sectional area of a $\frac{3}{8}$-in. rod is .11 sq. in. and the length of rod in one hoop of a spiral with a diameter of 21 in. is $3.14 \times 21 = 65.9$ in., the volume of a hoop is $65.9 \times .11 = 7.25$ cu. in. The distance between centers of hoops should not exceed $7.25 \div 2.39 = 3.03$, or say 3 in. Ans.

Columns With Lateral Ties.—The maximum allowable axial load on a short column reinforced with longitudinal bars and separate lateral ties is 80% of the allowable load for a spiral column with the same dimensions and longitudinal reinforcement. The longitudinal reinforcement in a tied column should consist of at least four bars with a diameter of not less than $\frac{5}{8}$ in., and the effective cross-sectional area of that reinforcement should be not less than 1% and not more than 4% of the gross area of the column section. The ties should be at least $\frac{1}{4}$ in. in diameter, and the distance between centers of ties should be not more than 16 bar diameters or 48 tie diameters. The concrete covering outside the ties should be at least $1\frac{1}{2}$ in. thick in a circular column and 2 in. thick in a square or rectangular column.

Long Columns.—In the case of an axially loaded column whose length h is greater than 10 times its least width d, the maximum allowable load may be found by determining the load as if the column were short and multiplying that result by $1.3 - .3\frac{h}{d}$.

DETAILS OF BUILDINGS

FOUNDATIONS

FOUNDATION BEDS

Materials.—The foundation bed of a structure is that part of the natural surface of the earth on which the structure rests. The materials usually regarded as suitable for foundation beds are solid rock, loose rock, earth, and sand.

Depth of Foundation Below Surface of Ground.—Foundations in earth should be carried to such a depth below the ground surface that frost will not reach them. Nearly all moist earth expands, or heaves, with freezing, and repeated freezing is likely to soften and disintegrate it. It may also be subjected to other disturbances near the surface. The depth of foundations may be dictated by conditions other than frost. Often a material that can safely support the loads on the structure cannot be found except at greater depths than are necessary to provide against frost.

The penetration of frost varies with the latitude. In the American Gulf States, ice seldom forms; while in the Lake region, the ground sometimes freezes to a depth of 5 or even 6 ft. Ordinarily, in the northern parts of the United States, subfoundations 4 ft. below the ground surface may be considered safe from injury by frost.

Not only is the soil likely to be firmer and harder a few feet below the surface, but the surrounding earth, by its weight, tends to counteract any movement and therefore to increase the bearing capacity of the foundation bed.

Required Area of Subfoundation.—In the case of foundations for ordinary structures where the weight is uniformly distributed over the whole of the foundation bed, the required area is equal to the total load coming on the foundation divided by the safe load per unit area. The safe bearing capacities of various soils are given in the accompanying table.

SAFE LOADS ON EARTH FOUNDATION BEDS

Kinds of Material	Loads in Tons per Square Foot
Hard sound rock	40
Medium hard rock	15
Hardpan overlying rock	10
Soft rock	8
Gravel	6
Sand, firm and coarse	4
Sand, fine and dry	3
Clay, hard and dry	3
Ordinary firm clay	2
Sand and clay, mixed or in layers	2
Sand, wet but confined	2
Clay, soft	1

Center of Pressure and Intensity of Pressure.—In Fig. 1 AB represents the width of a foundation and V the vertical component of the resultant of all the forces acting on a portion of the foundation 1 ft. long. The point, as e, at which V is applied to the foundation bed, is called the center of pressure.

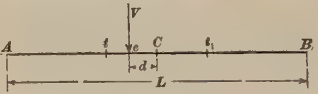


FIG. 1

When the force V is applied at the center C of AB, the intensity of pressure on the foundation bed is uniform and is equal to $\frac{V}{L}$. When the center of pressure is at a distance d from the center, as in the diagram, the intensity of pressure at the edge nearer the load, which is the maximum unit pressure, is

$$p_1=\frac{V}{L}\left(1+\frac{6d}{L}\right)$$

and the intensity at the other edge, or the minimum unit pressure, is

$$p_2=\frac{V}{L}\left(1-\frac{6d}{L}\right)$$

If the center of pressure falls outside the middle third tt_1, the value of p_2 is negative and the foundation is subjected to an uplift at the edge farther from the load. Hence, the center of pressure should always lie within the middle third of the foundation bed. When the center of pressure is at the edge of the middle third, the maximum intensity of pressure is $\frac{2V}{L}$.

SPREAD FOOTINGS

The term spread footings is applied to footings that are shallow in depth, and project far beyond the upper portion of the structure. The two types of spread footings most extensively used are the steel-beam grillage footing and the reinforced-concrete footing.

A typical grillage footing for a column is shown in Fig. 2. On the properly leveled foundation bed is laid a mat *a* of plain concrete. After it has hardened sufficiently, the grillage beams *b* and *c* are placed in tiers or layers, the beams of each tier being parallel to each other and at right angles to those of the tier below. The beams are kept the proper distance apart by means of bolts and separators *s*. The column base and the beams of each tier are usually set $\frac{3}{4}$ inch above the tier below as at *g*. The beams are encased in concrete.

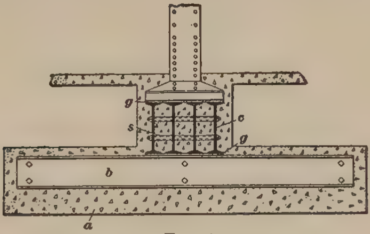


FIG. 2

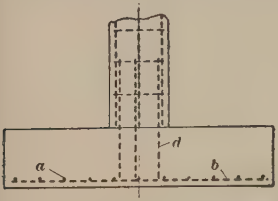


FIG. 3

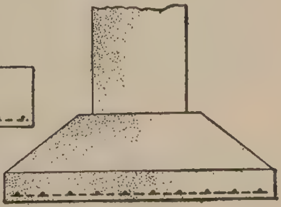


FIG. 4

A reinforced-concrete spread footing to support one column is usually made in one of three forms: (1) slab footing, Fig. 3, (2) sloped footing, Fig. 4, or (3) stepped footing, which consists of a reinforced-concrete slab and one or more steps poured monolithically.

In the usual arrangement of reinforcing rods in square footings the rods are placed in two layers, a and b in Fig. 3, at right angles to each other and parallel to the sides of the footing. Sometimes the rods are placed in four belts or layers, of which two are parallel to the sides of the slab and two are diagonal. The compressive stress carried by the longitudinal rods in the column can be effectively transferred to the footing by the dowels d in Fig. 3.

Wall footings are similar to column footings, but project only in a crosswise direction.

PILES

Piles that are driven in soft soil in order to sustain vertical loads are called bearing piles. They are usually of wood or concrete, but are sometimes of steel. Because of the frictional resistance between the surface of the pile and the surrounding soil, a pile can support a comparatively heavy load. The safe load on a pile is usually calculated by means of a formula, which is based on the results of tests. Let R denote the safe load or the bearing capacity of a pile; s, the penetration of the pile, or the average distance, in inches, that the pile moves under each of the last few blows of the hammer used for driving it; w, the weight of the hammer; and h, the fall, in feet, of the hammer at the last blow. Then, for drop-hammer pile drivers, the formula commonly used is

$$R=\frac{2wh}{s+1}$$

For single-acting air-hammer or steam-hammer pile drivers,

$$R=\frac{2wh}{s+.1}$$

For double-acting air or steam hammers,

$$R=\frac{2h(w+Ap)}{s+.1}$$

in which A = effective area of piston of hammer, in square inches;

p = mean effective air or steam pressure, in pounds per square inch.

Piling is sometimes driven so as to form a tight wall that prevents the caving of the face of a bank of earth. Such piling is known as sheet piling.

FIREPROOFING

GENERAL REMARKS

The fireproofing of buildings is accomplished either by enclosing a framework of steel, which in itself will soften and bend under the influence of great heat, with an incombustible material such as brick, structural clay tile, or concrete; or by forming the entire structure of a fireproof material, such as reinforced concrete, which will also supply sufficient strength for the various parts of the structure.

A good fireproofing material should resist not only intense heat but also the effects of water striking it when the material is heated. The New York City Building Code provides, in tests for fireproof floor construction, that a specimen of the floor shall be loaded with the designed floor load and exposed to a temperature of 1,700° F. for 4 hr. A stream of water shall then be directed against the under surface for 5 min. for each 100 sq. ft. of surface. To pass the test, the floor should not allow smoke to go through it, and must sustain its load with a deflection of not more than $\frac{1}{4}$ in. for each foot of span.

FIREPROOF FLOORS

Structural-Clay-Tile Arches.—In Fig. 1 is shown a side-construction structural-clay-tile arch, in which the air spaces, or cells, in the tile run parallel with the supporting beams. In this case, the skewbacks *a* fit snugly against the beams and cover their lower flanges. Another form of flange protection is shown in Fig. 2, in which soffit tiles *a* are held in place by the skewbacks.

The tile *b* in Fig. 1 is the key, and tiles *c* are lengtheners. The tiles in this system are laid with the joints broken, as indicated. The space between the top of the arch and the tops of the beams is filled with a concrete filling made of 1 part of portland cement and 10 parts of sand, cinders, and broken tile. Upon the concrete filling sleepers are laid at right angles to the beams and are generally secured to the beams, as shown in Fig. 3, by means of steel clips *a*. The spaces between the sleepers are filled with concrete to within

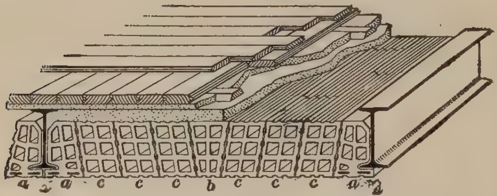


Fig. 1

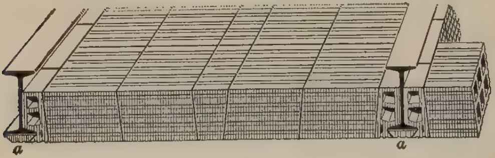


Fig. 2

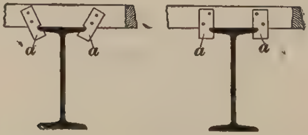


Fig. 3

½ in. of their upper surfaces. Tie-rods should always be used with hollow tile arches to take up the thrust of the arches. Plaster can be applied directly to the under surface of the arches to form the ceiling.

An end-construction structural-clay-tile arch is shown in Fig. 4, in which the air spaces in the blocks run perpendicular to the beams. The webs of the tiles as well as the outer shells convey the floor load to the supporting beams. On account of the greater strength of this system, it has to a great extent superseded the side-construction method.

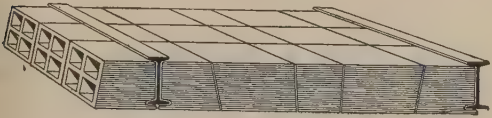


FIG. 4

A combination arch, formed of the end-construction arch with side-construction skewbacks, is shown in Fig. 2. This kewback affords a better protection for the beam. The tiles annot be laid with broken joints in this system and each rch is complete in itself.

The accompanying table gives the weight per square foot nd the allowable span between supporting beams for structural clay tile of various depths. The heavier weights are he ones commonly used. The lighter weights can be made if equired.

Centering for Flat Arches.—To support the tiles during aying, a firm centering is needed. A good form of centering s shown in Fig. 5. The 1-in. boards *a* which are dressed and et close together, rest on a 4″×4″ or 4″×6″ piece *b* that xtends parallel with the beams and is midway between them. he piece *b* is suspended by **T**-headed bolts *c* from similar eces *d*, which are laid across the tops of the beams. The es forming the **I**-beam protection are put in place first and, they are separate pieces, are laid on the boards directly neath the beams; or, if the **I**-beams are protected by the

WEIGHT OF LOAD-BEARING STRUCTURAL CLAY TILE FLAT-ARCH FLOOR CONSTRUCTION

Depth of Arch Inches	Weight Pounds per Square Foot		Allowable Span Between Beams							
			Side Construction				End Construction			
	Side Construction	End Construction	Arch Set Flat		Arch Set With Slight Camber		Arch Set Flat		Arch Set With Slight Camber	
			Feet	Inches	Feet	Inches	Feet	Inches	Feet	Inches
6	24 to 26	20 to 25	4	0	4	6	4	6	5	0
7	26 to 28	22 to 26	4	6	5	6	5	0	5	9
8	27 to 32	24 to 30	5	0	6	0	5	6	6	6
9	29 to 36	26 to 34	5	6	7	0	6	0	7	0
10	33 to 38	28 to 36	6	6	7	6	6	6	7	6
12	37 to 44	30 to 40	7	0	8	6	7	6	9	0
15		37 to 50					9	0	10	0

skewbacks, as at *e*. the latter are set first. The bolts *c* are then tightened so as to bend the boards slightly and form a camber, or crowning, which should be $\frac{1}{4}$ in. for a 6-ft. span.

In setting the tiles, the pieces should be adjusted so that the surfaces will abut properly. Only the best portland-cement mortar should be used, the joints should be thin, and care should be taken that the mortar does not become pressed out. The centering should be kept in place until the mortar between the tiles has set, which takes from 12 to 36 hr. When the centering is removed, the arch should have a level surface, with no open joints or projecting tiles. If holes in the floor are required, they may be punched in a tile and closed afterward with broken tile and mortar; or, if a side-construction arch is laid, a tile may be temporarily omitted.

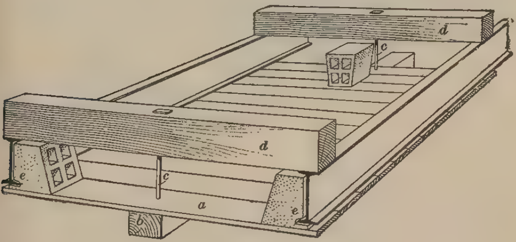


FIG. 5

Reinforced-Concrete Floors.—Another kind of fireproof construction for floors consists of reinforced concrete used in connection with steel beams or with reinforced-concrete beams. The reinforcement may be in the form of wire cables, square or diagonal wire mesh, rods, bars, steel plates, or unit trusses. These floors are built on wooden forms, which are left in place until the concrete has set.

The floor system shown in Fig. 6 has rods that are embedded in a slab of concrete. Some of these rods extend across the steel beams and others run parallel with the beams. The beams may be of steel, as shown in the figure, or of reinforced concrete. If of concrete, the beams and slabs are cast at the same time.

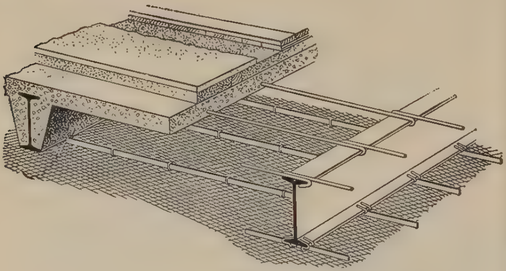


FIG. 6

In Fig. 7 is illustrated the use of a wire cloth for reinforcement. This mesh is welded together at the joints or crossings. The mesh is made into rolls from 60 to 300 ft. in length, thus permitting of long spans and of forming a continuous tie across an entire building. Diagonal wire mesh and expanded metal are used in a similar manner. The supporting beams may be of steel or of reinforced concrete.

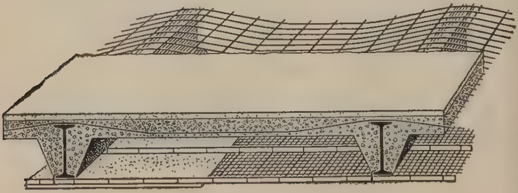


FIG. 7

Slab-and-Beam Floor Construction.—Reinforced-concrete floors are formed by using thin concrete slabs supported on concrete joists or beams. In Fig. 8 are shown steel forms *a*, known also as tin pans, metal pans, or metal cores, which are set on boards *b*. Between the pans are formed concrete beams *c*, which are reinforced by the rods *d*. The slab *e* is poured at the same time as the beams. The reinforcing rods rest on the lower flanges of the **I**-beams *f*. The pans are provided with special ends *g*, which allow the forming of a protection *h* for the **I**-beams. When the concrete has been poured

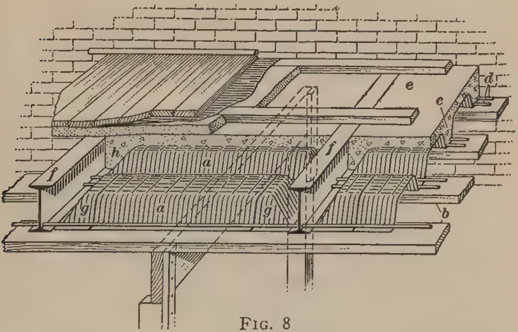


Fig. 8

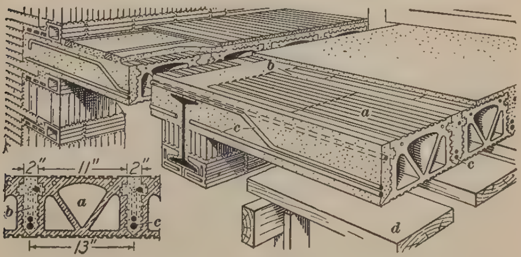


Fig. 9

and has set, the pans may be removed, or they may be allowed to remain in place. If a flat ceiling is desired it may be hung below the I-beams.

Natcoflor System.—A long-span floor system, known as the Natcoflor system, is shown in Fig. 9. The floor consists of tile blocks *a* having recesses in the sides, and concrete beams *b* reinforced with rods *c*. The floor is built on a centering of 2-in. planks *d*.

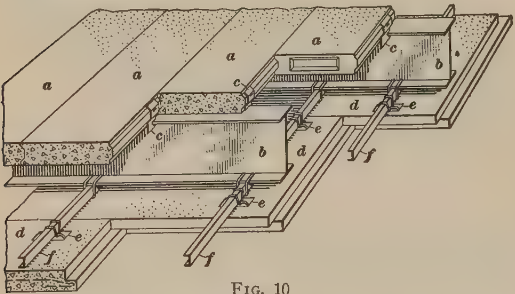


FIG. 10

Gypsum-Slab Floor Construction.—A floor construction consisting of precast, light-weight gypsum slabs in connection with light-weight joists is shown in Fig. 10. Gypsum slabs *a*, that are about 10 in. wide, 72 in. long, and $2\frac{1}{2}$ in. thick and are reinforced with wire mesh, are placed over junior or light-weight steel beams, bar joists, lattice joists, or other forms of light-weight joists *b*. These gypsum blocks are made usually with tongue-and-groove edges and with recessed ends. The slabs are connected to the beams or joists by means of clips *c*.

Selection of a Fireproof Floor System.—The question of choosing the best floor system out of the many of nearly equal merit hinges largely on the cost, as any of those that have been described can be made amply strong and, as a rule, entirely fireproof, if properly constructed. The floor that is lightest in weight is generally the best, as the weights and sizes of the beams, girders, and columns are less, and the cost of the structure is correspondingly reduced.

CEILINGS

Ceilings may be plastered directly on the under side of the structural-clay-tile arches. Where the arch or slab does not present a flat under surface, a flat ceiling may be hung from the under side of the beams, as shown in Figs. 6 and 7. In stores, warehouses, and other buildings where a flat ceiling is not necessary, the plaster may be applied directly to the slab, thus saving the cost of metal furring and lathing, or the concrete may be painted.

Gypsum slabs may be suspended below the floor construction as shown in Fig. 10. At *d* are reinforced gypsum slabs about 2 in. thick. Rods *e* embedded in the slab are exposed at the pockets at each end of the slab and may be wired to channels *f*, which in turn are wired or clipped to the beams or joists. Plaster may be applied directly to the slabs.

ROOFS

Roofs on fireproof buildings are often flat as a matter of economy. In such cases they are built like floors, and any of the forms described may be used. The weight or load being somewhat less, the construction may be correspondingly lighter.

PARTITIONS

Fireproof partitions are made of structural-clay-tile or gypsum blocks, and cement or plaster on metal lath. Tiles are readily available and are laid up in cement mortar. Partitions of this material are heat-proof, sound-proof, and vermin-proof. Openings for doors and windows are formed of wooden or channel iron bucks. The tile or gypsum blocks should be laid with broken joints, and the partitions should be tightly wedged at the ceiling. The accompanying table gives the standard sizes and weights of structural clay tiles up to 6 in. thick, and the safe heights of partitions.

Blocks made of gypsum or plaster of Paris mixed with a tough fiber are used in building partitions. They are somewhat lighter in weight than structural clay tiles and are made in larger sizes, thus economizing in weight, labor, and mortar. These blocks can be cut with a saw and will hold nails well.

A method of forming a fireproof door jamb in which no wood is used is shown in Fig. 11. A 1½-in. channel stud *a* runs to the ceiling on each side of the door and a 2-in. channel *b* is fastened to it to form a buck. A jamb *c*, of sheet metal, is fastened to the channel buck and a sheet-metal trim *d* is fastened to the buck and jamb by screws *e*. The jamb is reinforced at the points where the hinges and locks occur by strips of metal *f*. This treatment makes an absolutely incombustible and practically fireproof door jamb and trim.

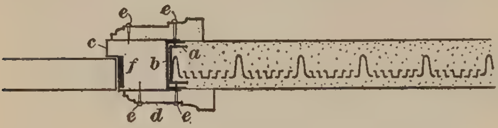


FIG. 11

SIZES AND WEIGHTS OF STRUCTURAL CLAY TILES FOR PARTITIONS

Thickness Inches	Standard Size Inches	Weight per Square Foot Pounds		Safe Height of Partition Feet
		Load Bearing	Non Load Bearing	
2	2×12×12	—	14	9
3	3×12×12	—	15	12
4	4×12×12	20	16	16
6	6×12×12	30	25	20
8	8×12×12	36	30	24
10	10×12×12	42	35	—
12	12×12×12	52	40	—

Partitions on metal lath that are thicker than 2 in. are generally made hollow. A covering of lath is placed on each side of the metal studding and both sides are plastered.

COLUMNS AND GIRDERS

Columns.—Columns should be protected with not less than 2 in. of fireproofing material. For a round cast-iron column, segmental blocks of structural clay tile are sometimes used. As shown in Fig. 12, these blocks *a* are made with lugs on the inner sides which rest against the column. They are set with the joints broken and are tied together by metal binders *b*.

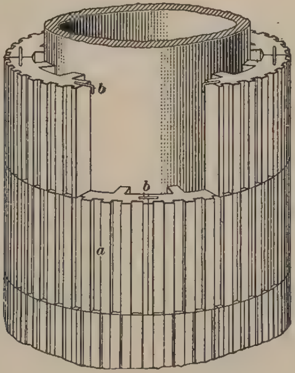
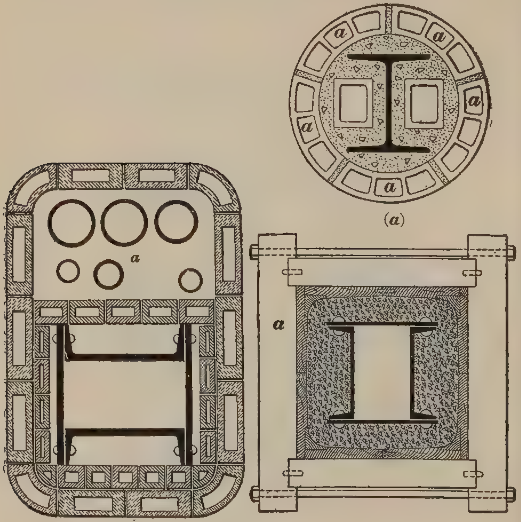


FIG. 12

In Fig. 13 (*a*) and (*b*) are shown methods used to fireproof columns of different shapes with structural clay tile. These tiles, *a* in view (*a*), are set with breaking joints, and are tied with copper wire at intervals of 1 ft. or so. Where pipes are run up beside the column, they should be placed as shown at *a* in (*b*), so that it will not be necessary to destroy the fireproof shell of the column if it becomes necessary to get at the pipes.

Concrete is a valuable material for fireproofing columns, as it is an excellent fire-resistant material. A column covered with concrete is protected against oxidation. The materials used for making the concrete can be obtained in almost any locality and they can be mixed and applied with cheap labor.



(*a*)

(*b*) (*c*)

FIG. 13

A form *a* in Fig. 13 (*c*) is bolted around the column, and concrete is poured into the space between the form and the column. After the concrete has set for a few days, the mold or form may be removed, leaving the completed column, and the form may be used elsewhere. Upon the surface of the concrete, plaster may be applied.

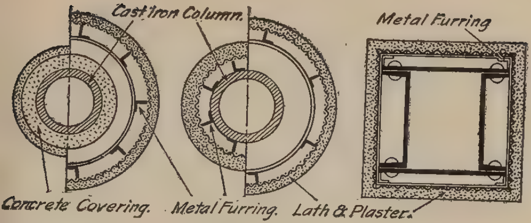
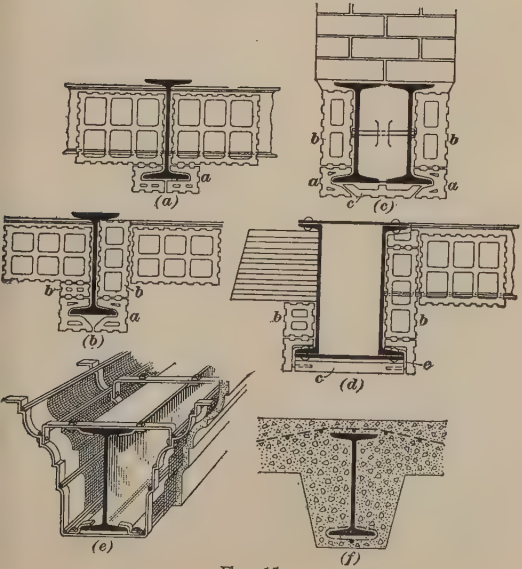


FIG. 14



(a) (c) (b) (d) (e) (f)

FIG. 15

Gypsum blocks may be used to fireproof columns in practically the same manner as described for structural clay tile.

Columns are sometimes covered with metal furring and lathing, as shown in Fig. 14. The finished shape of the column is laid out approximately in metal furring consisting of angle irons, flat bars, etc., and the metal lath is wrapped around the furring and wired to it. The lathing is then plastered. The enclosed air space helps to provide protection for the column.

Girders.—Girders are fireproofed with structural clay tile, as shown in Fig. 15. For single **I**-beam girders, shown in (*a*) and (*b*), clip tiles *a* are used to protect the bottom flanges, and plain tiles *b* are used to cover the sides of the girder. For double or wide girders, as shown in (*c*) and (*d*), the bottom flanges are covered with clip tiles *a*, and the sides by plain tiles *b*. The soffit tile *c* in (*d*) is held in place by iron clamps *e*. In (*e*) is shown a method of protecting a girder with metal furring and lathing. In (*f*) the girder is covered with a mass of concrete, which protects it from fire and oxidization.

CONSTRUCTION WITH HOLLOW TILE

Typical Details for Dwelling.—In Figs. 1 and 2 are shown various details used in the construction of a dwelling. The wall in Fig. 1 (*a*) is started by placing the concrete footing *a*. The starting course of tile *b* is then laid. Where the tiles come in contact with earth, they should be glazed or covered on the outside with a heavy coat of waterproof cement. The sill *c* of the cellar window is shown of stone that is backed up with tiles *d*. The lintel *e* over the window is formed of 12″×12″×12″ tiles filled with concrete and reinforced by steel rods in the lower cells.

The window sill *c* in Fig. 1 (*b*) is formed of tiles, 2 in. or 3 in. thick, that project beyond the face of the wall; this is finished in plaster or stucco the same as the wall of the house. A wash and drip are run on the sill as shown. Another form of lintel applicable to both doors and windows is shown at *e*. This lintel is of concrete and tile. It is formed in a wooden mold, which is supported on struts that rest upon the sill below until the lintel is thoroughly set. When the mold is in place, 2-in.

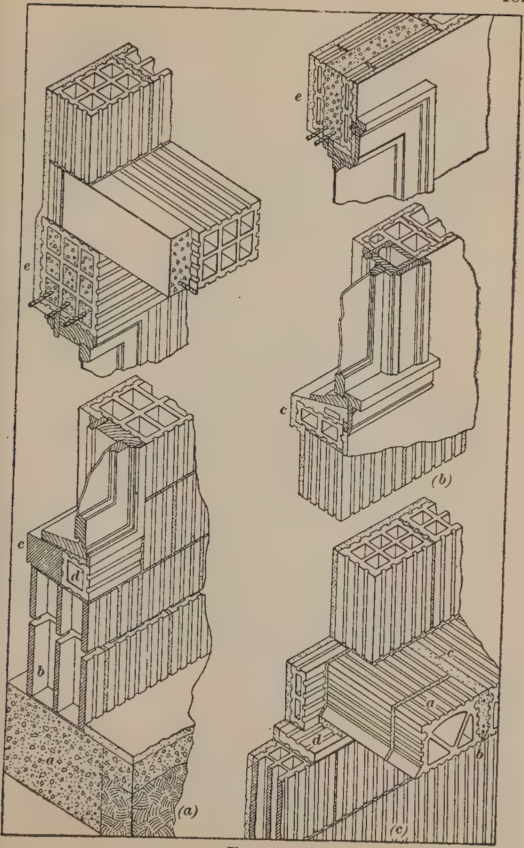


FIG. 1

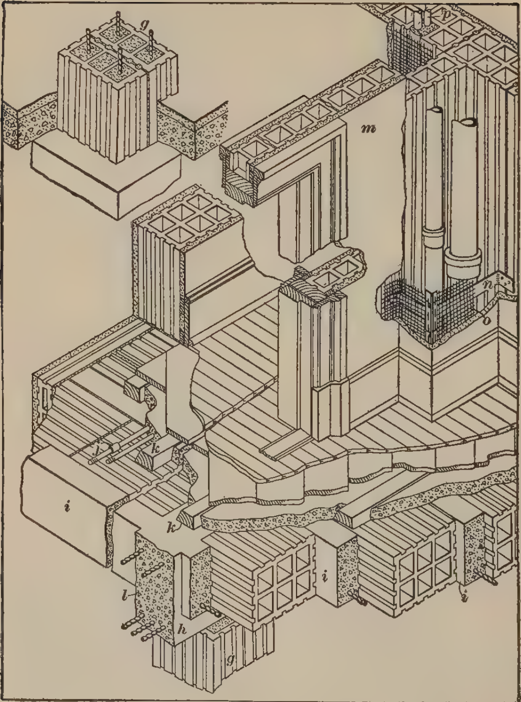


FIG. 2

tiles are laid along the sides of the mold and flush with the faces of the wall. Rods are then laid near the bottom of the space between the tiles and concrete is poured in.

Floor Construction.—In Fig. 1 (*c*) is a section of a wall which supports a reinforced-concrete and tile floor. A tile is shown at *a* and reinforcing rods at *b* in the concrete beam *c*. The tile rests on a flat tile *d* which is placed over the wall tile.

Another type of fireproof floor, in which joists of reinforced concrete are used and tiles are placed between them, is shown at *i*, Fig. 2. A section through this kind of floor is shown in Fig. 3. The centering, or false work, necessary in constructing this floor consists of planks laid 16 in. on centers and supported on stringers *a*. The tiles are set with the edges resting on these planks, as shown, leaving a space between the tiles of sufficient width to receive the joists. Rods *b* are then placed near the bottoms of the spaces and concrete *c* is poured in.

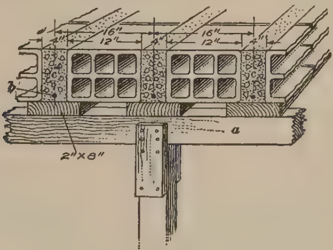


Fig. 3

Sleepers *k*, Fig. 2, are laid on top of this construction and the spaces between them are filled with cinder fill, or concrete made with cinders. Pipes for water and gas and wiring conduits, etc. are concealed within the fill as at *j*.

The floor is supported by reinforced-concrete girders *l*, which rest on piers *g*. Each pier consists of tiles, in the cells of which are placed reinforcing rods and concrete, as shown in the upper left-hand corner of Fig. 2.

The partition *m*, Fig. 2, is built of hollow tile and is plastered on both sides. A pipe chase is furred out with metal furring *n* and enclosed with metal lath *o*, upon which the plastering is applied. A method of making a pipe chase in the outer walls is shown at *p*. In this case, the inside webs of the tiles are broken away and the pipes are inserted, after which the opening is covered with wire lath and plastered. In some cities, cutting of hollow tile to form chases is forbidden.

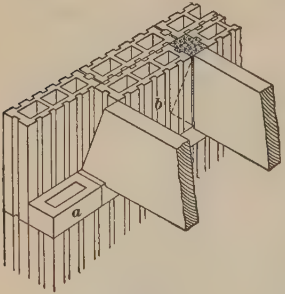


FIG. 4

Supporting Wooden Floor Joists.—In Fig. 4 is shown a method of resting floor joists on hollow-tile walls. The joists are spaced 16 in. on centers, which allows the placing of a 12-in. tile *b* between the ends of each pair of joists. A row of brick stretchers *a* is often used to support the ends of the joists, when the depth of the joists is less than the height of the tiles.

Instead of a course of bricks being used to support the joists, a course of 1-in. tile which covers the entire thickness of the wall, as shown at *b*, Fig. 5, is often used. In each of these methods the spaces between the ends of the joists and the tiles are generally filled with concrete.

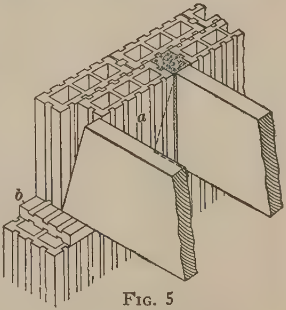


FIG. 5

In Fig. 6 is shown a third way of supporting wooden floor joists; in this case joist hangers are used. This method has the advantage that the joists do not enter the wall and weaken it.

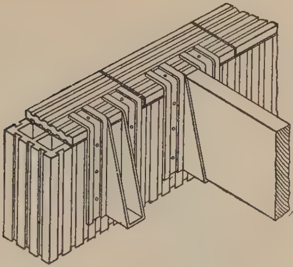


FIG. 6

Fastening Roof to Wall.—In Fig. 7 is given a method of bolting the plate *a* to the top of the wall. The bolt is held in

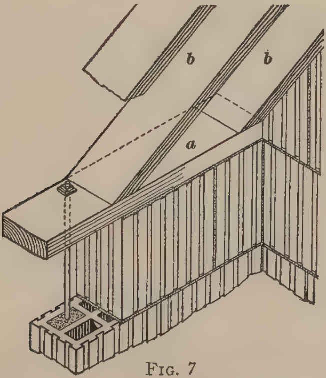


FIG. 7

position and the air cell in which the bolt is set is filled with cement mortar. The rafters *b* rest on the plate in the regular manner.

Veneering With Brick.—In Fig. 8 is shown a method of veneering a hollow-tile wall with brick. The stone water-table *a* rests on the thicker tiles of the cellar wall and upon it the brickwork is built in front of the tiles. At every tenth or eleventh course of brickwork, the brick veneer is tied to the tile backing as at *b*. This bonding course is backed up by a row or course of thin tile *c*.

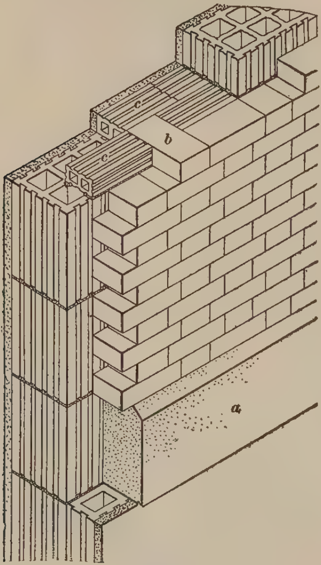


FIG. 8

Finish of Hollow-Tile Walls.—Hollow-tile walls, when not veneered, are generally finished with stucco on the outside. The tiles are first thoroughly wet, and a scratch coat, consisting of 1 part of portland cement, 3 parts of sand, and not more than 10% of hydrated lime or lime putty, is applied, thoroughly pressed into the grooves in the blocks, and well scratched. The finishing coat should be about $\frac{1}{4}$ in. thick and can be put on to produce different effects of texture and color. By using a white cement and marble screenings, a white marble-like effect is obtained; by using gray cement and brown sand, a warm gray color is obtained.

The cement may be dashed on, or thrown on with a trowel, and a rough texture obtained, or the surface may be troweled and made comparatively smooth. Colored pebbles, marble chips, etc. may be pressed into the surface. The colors of the stones and chips will then appear and give a tint to the entire surface.

ARCHES

Forms and Parts.—The general forms of arches are semicircular, segmental, pointed, elliptic, etc., the name being determined by the inner curve. The various parts of an arch are marked in Fig. 1. The inner curve is called the intrados.

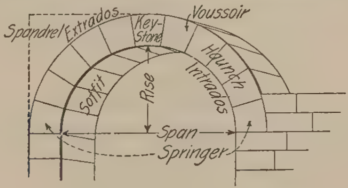


Fig. 1

The outer curve is termed the extrados. The soffit is the concave surface of the arch. Voussoirs or ringstones are the pieces composing the arch; the center or highest stone is termed the keystone or keyblock. The first courses at each side are called springers, except in the case of segmental arches, in which they are termed skewbacks. The voussoirs between the skewbacks or springing stones and the keystone collectively form the flanks or haunches, and the spandrels are those portions of the wall above the haunches and below a horizontal line through the crown of the extrados.

The span is the horizontal distance between jambs, and the perpendicular distance from the springing line to the highest part, or crown, of the soffit is the rise.

The joints of circular and segmental arches radiate from a single center. In arches having two or more centers, the joints in each arc of the curve radiate from their respective centers. The joints of elliptic arches are found thus: Draw lines from each point (spaced off on the intrados or extrados) to the foci, as shown in Fig. 3 (*n*), and bisect the angles thus formed; the bisecting lines will give the direction of the joints.

Examples of Arches.—In Fig. 2 (*a*) is shown a semicircular arch, of which *ab* is the springing line and *cd* the rise.

In (*b*) is shown a segmental arch; the center *a* is taken on the line *ab*, which bisects the span *cd*. The radius of this arch equals approximately the square of the span divided by eight times the rise.

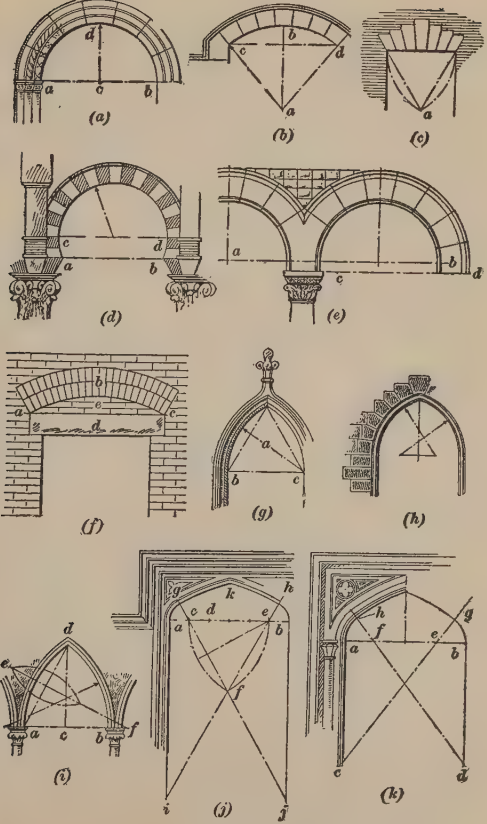
In (*c*) is shown a flat arch built of wedge-shaped voussoirs, together serving as a lintel; the joints radiate from a center at the vertex of an equilateral triangle of which the span is one side.

In (*d*) is shown a Moorish, or horseshoe arch, the springing line *ab* being below the center from which the curve is struck, making a sweep of about 230°. A similar form is the pointed Moorish arch, differing from (*d*) only above the line *cd*, above which it takes the form of a two-centered or pointed arch. These two arches are called stilted arches, from the fact that the center is raised above the springing line.

Another example of stilted arch is shown in (*e*), in which the arch centers are on the line *ab*, and the springing line *cd* is below it.

In (*f*) is represented a brick relieving arch *abc*, intended to carry the weight of the wall above; by this construction the lintel *d* merely sustains its own weight and that of the small brick segment *e*.

In (*g*), (*h*), and (*i*) are shown methods for drawing two-centered, pointed, or Gothic arches. In (*g*) is represented an


d
a
c
b
(a)
b
c
d
a
(b)
a
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c
d
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b
(d)
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h
c
d
e
a
b
f
i
(j)
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g
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e
a
b
c
d
(k)

FIG. 2

equilateral arch, or one in which the radius *a* of each curve is the same length as the springing line *bc*. In (*h*) is shown an arch in which the centers are taken inside the jamb lines, thus flattening the arch; in this example, the radius is equal to three-quarters of the span. In (*i*) is shown a pointed arch having a height *cd*, greater than the span *ab*. To find the centers, proceed as follows: Draw the line *ad*, and bisect it by *ef*, which cuts the springing line at *f*, on *ab* produced. Then with *f* as center and a radius *fa*, one side of the arch may be drawn, the other half being similarly found.

In (*j*) and (*k*) are shown examples of four-centered Gothic, commonly called Tudor, arches. In (*j*) is represented an arch in which the given span *ab* is divided into six equal parts, as at *c*, *d*, *e*, etc. To find the centers for the longer radii, with *c* and *e* as centers, and a radius *ce*, describe arcs intersecting at *f*; draw *fc* and *fe*, and produce these lines to *g*, *h*, *i*, and *j*; the last two points will be the required centers. With *c* and *e* as centers, and a radius *ca*, describe arcs *ag* and *bh*; with *i* and *j* as centers, and a radius *ih*, describe the arcs *hk* and *gk*.

In (*k*) is shown an arch of similar construction, but the span *ab* is divided into four equal parts. The distances *ac* and *bd* are each made equal to *ab*; lines are then drawn from *c* and *d* through *e* and *f*, and produced to *g* and *h*; the arcs are then struck in a manner similar to that shown in (*j*).

In Fig. 3, (*l*) represents an ogee arch, which is stilted one part in seven of the total height. The span is divided into six equal parts, and the centers for the lower arcs are taken at *a* and *b*, at each side of the center line *cd*; the lower and upper arcs are tangent on the outer line of the molded architrave, the position of *e* and *f* being determined by the width of the neck at *g*

In (*m*) is shown a three-centered arch, having the span *ab* given. To lay out this arch, divide *ab* into four equal parts, as at *cde*. From *a* and *b* as centers, with a radius *ae*, describe the arcs *ef* and *cf*, intersecting on the center line *fg*. From *c* and *e* as centers, with a radius *ca*, describe the arcs *ah* and *bi*; and from *f* as a center, with the radius *fh*, describe the arc *hgi*, completing the figure.

In (*n*) is shown a three-centered skew arch, which closely approaches an elliptic curve in form. To construct the arch, having given the required span *ab* and the height *cd*, proceed as follows: Take any point *e* on *cd*, and make *af* and *gb* equal to *ed*. Draw *fe*, and bisect this line by the line *hi*, cutting the center line *dc* at *h*. Draw *hfk* and *hgj*; with *f* and *g* as centers, draw the arcs *ak* and *bj* and with *h* as a center draw the arc *kdj*

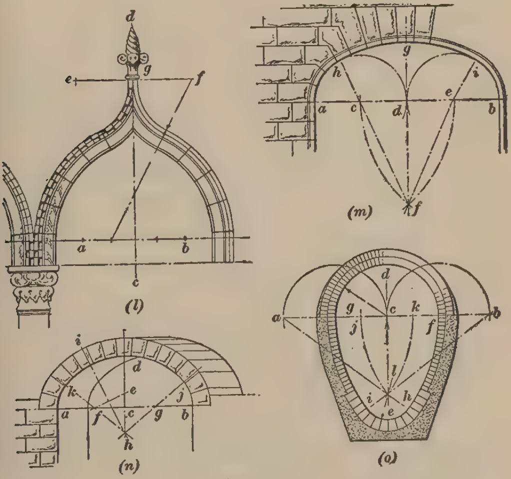


FIG. 3

In (*o*) is represented a form of arch used for egg-shaped sewers. To lay out the curves, draw the springing line *ab* and the center line *de*. From *f* and *g* as centers, with a radius *gc*, describe arcs cutting the springing line in *a* and *b*; with these points as centers, and a radius *af*, describe the arcs *fh* and gi. Divide the span gf into four equal parts by points j, c, and k, and from the points a and b as centers, with a radius ak, describe arcs intersecting the center line de at the point l; now, with l as the center, and a radius lh, describe the arc hei draw the upper curve gdf, which is a semicircular arc struc from the common center c, thus completing the figure.

CHIMNEYS AND FIREPLACES

CHIMNEYS

In planning chimneys the points to be considered are the height, and the number, size, and arrangement of the flues. Attention must also be given to the location in respect to valleys, etc. on the roof. To make the chimney draw properly, a separate flue should be provided, extending from each fireplace to the top of the chimney. For ordinary stoves and small furnaces, the flues may be 8 in.×8 in.; but if the furnace is large, it is better to make the flue 8 in.×12 in., and the same size should be used, when possible, for fireplaces having large grates. Flues are sometimes only 4 in. wide; but are then easily choked with soot and difficult to clean, so that a flue should not be less than 8 in. wide.

Flues should always be lined with some fireproof material; in fact, the building laws of large cities so require. The lining is usually fireclay tile. If the pipe used is round, the space between it and the walls of the chimneys may be utilized for ventilation.

Where flue linings of fireclay or terra cotta are used the outer walls of the chimney are usually made 4 in. thick. The walls should be made 8 in. thick if no flue linings are used and the flues should be carefully pointed up and not plastered. The brick partitions between flues are called withes.

Whenever it is necessary to change the direction of the flue, the diversion should be effected by easy bends, and not by sharp turns, which retard the passage of smoke. Chimneys should extend above the highest point of the building or of those adjoining; otherwise they are not likely to draw. This fault may be remedied, when the chimney is not carried high enough, by using a hood having two open sides; but as hoods are unsightly, their use should be avoided, when possible.

In the accompanying table are given dimensions of rectangular and round flues also their effective areas.

For fireplaces, in which it is intended to burn anthracite coal, the flue should have an area equal to one-twelfth or one-fifteenth of the area of the fireplace opening. Where wood or bituminous coal is to be used, the flue area should be one-tenth or one-twelfth of the area of the fireplace. Thus, for a fireplace 36 in. wide and 30 in. high designed for burning wood, the flue lining should be from one-tenth to one-twelfth of 36×30, or 1,080 sq. in., or from 108 sq. in. to 90 sq. in. From the accompanying table it is found that an 8½″×18″ flue has an effective area of 100 sq. in. and that a 12 in. round flue has an area of 113.1 sq. in. Either of these flues may be used. If anthracite coal is to be burned, the smallest flue should be one-fifteenth of 1,080=72 sq. in. From the table, it is found that an 8½″×13″ rectangular or a 10-in. round flue will suffice.

DIMENSIONS AND EFFECTIVE AREAS OF FLUES

Rectangular Flue		Round Flue	
Outside Size Inches	Effective Area Square Inches	Inside Diameter Inches	Inside Area Square Inches
4½×8½	21	6	28.3
4½×13	36	8	50.3
7½×7½	31	10	78.54
8½×8½	41	12	113.1
8½×13	70	15	176.7
8½×18	100	18	254.4
13×13	99	20	314.1
13×18	156	22	380.13
18×18	195	24	452.3
20×20	234	27	572.5
20×24	278	30	706.8
24×24	346	33	855.3

The part of the chimney projecting above the roof should be laid up with strong cement mortar so as to prevent disintegration and should be covered with a protecting cap of stone. This cap may be pierced with holes to match the flues as shown in Fig. 1 where *a* is the capstone of the chimney with holes *b* cut through flush with the inner edge of the flue lining and covering the joints between the brickwork and the linings. A chimney cap that is not perforated is shown at *a*, Fig. 2. This cap is supported at the four corners by small brick piers between which the smoke passes through the spaces *b*. This cap prevents rain from falling directly into the chimney.

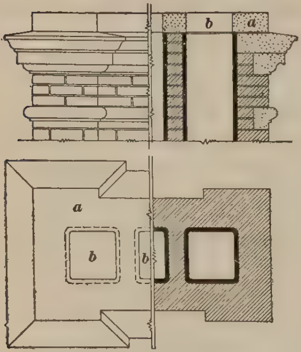


FIG. 1

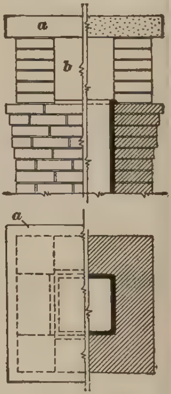
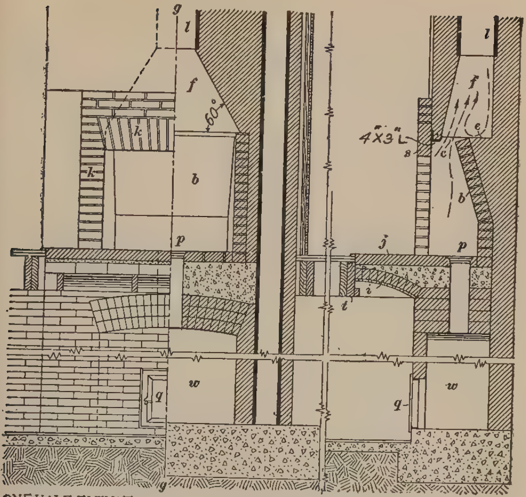


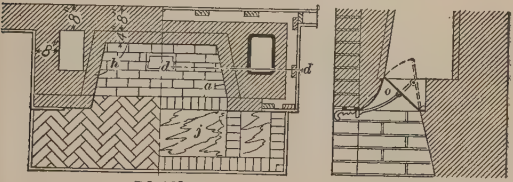
FIG. 2

FIREPLACES

The general construction of a fireplace in a dwelling is shown in Fig. 3. The projection of the chimney into the room is called the chimney breast. The height of a fireplace should be about 2 ft. 6 in. to 2 ft. 8 in. above the finished floor, its depth from 16 in. to 24 in. and its width from 2 ft. to 5 ft. A properly



ONE HALF ELEVATION SECTION *d*-*d* SECTION *g*-*g*



PLAN PAT. THROAT & DAMPER

FIG. 3

designed fireplace should have sloping sides, as shown at *a*, with a slope of about 3 in. in 1 ft., so as to reflect the heat into the room.

The back *b*, should slope forwards and form the throat *c*, which should be from 2½ in. to 4 in. in depth and of the same width as the fireplace opening. The total area of the throat should be not less than that of the flue lining. The throat should be at least 2 in. or 3 in. above the top of the opening of the fireplace as shown at *s*, and as near the front of the fireplace as possible.

The smoke shelf *e*, is an important feature. It prevents the air rushing down when the fire is started and forcing smoke into the room.

The smoke chamber *f*, is formed by drawing the brickwork together at an angle of 60° on the sides until it is reduced to the dimensions of the flue lining. The fireclay flue lining *l*, is then started, being supported by the brickwork, as shown.

The hearth *j* is extended in front of the fireplace so as to catch embers that may fall out of the fire. It is supported on the trimmer arch *i* consisting of a single rowlock arch about 20 in. wide springing from the chimney to the header *t*. This arch is laid upon a wooden center, which is left permanently in place to receive the lath and plaster of the ceiling. Upon the trimmer arch, the hearth is built up of cement or concrete and is finished in tile, marble, or brick. The hearth should extend at least 12 in. on each side of the fireplace opening.

Patent throats and dampers *o*, are used in good work, and are made of cast iron with a properly shaped throat and a hinged damper, which can be adjusted to regulate the draft as desired. These devices serve at the same time as supports for the brickwork of the front of the smoke chamber.

Finish of Fireplaces.—Firebrick, soapstone, and metal are used for the back and sides, or lining *h*, of the fireplace. Firebrick forms a most efficient non-conductor and when laid up neatly forms an excellent lining. Cast-iron linings are made in ornamental patterns, which are used where it is intended to use grates. These linings should be backed up with firebrick.

The facings *k* of a fireplace may be formed with brick, marble or tiles; the hearth should be finished to correspond.

Ash Trap.—At *p* an ash trap is shown opening into a chute that leads to an ash-pit *w*, formed in the body of the chimney in the cellar. This pit is furnished with a cleanout door *q* through which the ashes are shoveled out.

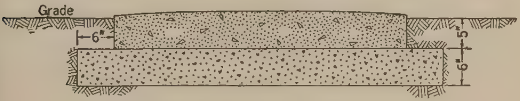
MISCELLANEOUS FEATURES

CONCRETE SIDEWALKS

For a plain concrete sidewalk, the subgrade must have uniform bearing power. Unless the subgrade soil is dry and well drained, the sidewalk should be installed on a 6-in. cinder or gravel fill which should be well tamped or rolled. If installed on existing soil, all soft spots should be filled and unusually hard spots should be loosened and tamped.

Concrete walks should be laid in sections not over 6 ft. square. Alternate squares should be laid first and the intermediate spaces should then be filled. Expansion joints should be provided approximately 50 ft. apart. The expansion joints should be filled with bituminous material, and may be dusted with cement. Expansion and construction joints should be rounded off with an edging tool to prevent chipping of the concrete edges.

Slabs are usually made 5 in. thick and are crowned slightly or are pitched to one side, except in cases where the walks pitch lengthwise. In many localities, ordinances give the width and pitch of sidewalks. A section through a typical concrete sidewalk is shown in the accompanying illustration.



Mix for the slab should consist of approximately 1 part portland cement, 1½ parts of fine aggregate, well graded from ¼ in. down, and 3½ parts of coarse aggregate well graded in size from ¼ in. up to 1½ in. Not more than 6 gal. of water should be used to each sack of cement. The concrete should be thoroughly compacted by tamping and spading. The slab may be finished at the final level and finished by screening, floating, or troweling.

If a special topping is desired, it may be installed as a separate finish, preferably the same day and before the structural part of the slab has hardened. Such a finish may be in the proportions of 1 part portland cement, 1 part sand, and from 1½ to 2 parts of coarse aggregate. The sand should be well graded from ¼ in. down, and the coarse aggregate should be graded from ⅛ to ⅜ in. The mixing water, including the surface moisture in the aggregate, should not exceed 5 gal. per sack of cement. As the durability of the wearing surface depends upon the strength of the aggregate, there should be as much aggregate at the surface as possible. Where an extremely durable wearing surface is desired, granite or trap rock aggregates are used.

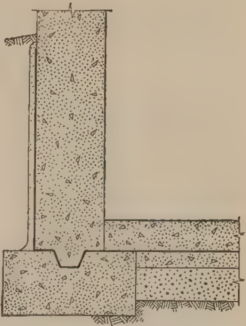
In general, a sidewalk should be kept from drying out for at least 7 days. If high-early-strength portland cement is used, the period should be not less than 3 days. Curing may be accomplished by covering the sidewalks with 1 in. of sand that is kept moist with waterproof paper or with canvas. Sidewalks should be sprinkled at regular intervals during the curing period. Proper curing increases the strength and wearing quality and reduces shrinkage and the tendency to crack.

Although many sidewalks are made from plain concrete it is often advisable to provide at least light steel mesh reenforcing.

WATERPROOFING WALLS

A damp basement may be avoided by conveying the ground water away from the basement or by treating the basement walls and slab with waterproofing applications or by a combination of both methods. To convey the water away from the walls, a trench approximately 18″ wide should be left next to the wall. An open-jointed tile drain should be laid at the bottom and the rest of the trench should be filled with broken stone. The tops of the joints in the drain should be loosely covered with roofing paper.

Good workmanship is the best precaution against the penetration of moisture. Care should be taken to fill all joints in masonry walls below grade. The mortar should consist of 1 part portland cement, .25 part hydrated lime, and 3 parts sand. Concrete for walls below grade should be thoroughly mixed and should be impermeable.



Basement walls may be dampproofed against the average soil condition by applying one coat of creosote oil and two coats of coal-tar pitch. The pitch should be heated so as to flow freely but not above 350° F. Dampproofing should be applied only to dry and smooth surfaces, and all cracks and joints in the masonry should be carefully pointed. The dampproofing should be protected with a 1″ coat of 1:3 portland-cement mortar troweled smooth, leveled at the top, and coved out to the edges of the footings.

For dampproofing purposes, numerous paints for interior application are available. These should always be used in accordance with the manufacturer's specifications. However, where there are differences of temperature, expansion and contraction will usually cause cracks; and in most cases paint can be considered only a temporary measure.

Where the soil is wet and water pressure is exerted against the foundation walls, it is usually necessary to install 3-ply membrane waterproofing. For severe conditions this waterproofing should extend under the entire floor, as shown in the accompanying illustration.

Basement walls are frequently coated on the interior with plaster or some other form of finish. Where the walls are of hollow block or tiles, the plaster is sometimes applied directly to the inside surface with the thought that the voids in the masonry units will prevent the moisture from penetrating to the plaster. This is a dangerous practice as moisture will frequently travel through the joints. In addition, the plaster applied directly to the basement wall is cooled by the earth adjoining the wall; and, when it is cooler than the room temperature, it acts as a condensing surface for the moisture in the air. If finished basement rooms are desired, it is best to fur exterior walls.

EFFLORESCENCE

On completed masonry there is often visible a light gray discoloration called efflorescence. Efflorescence is caused by moisture in combination with soluble salts in the masonry units or mortar. These salts in evaporating are deposited on the surface in powder or crystal form. Generally, efflorescence is due to the mortar used, as few masonry units contain soluble salts. It is more prevalent in walls not reached by sunlight, as the sun will draw out the moisture and reduce the amount of efflorescence.

The most common causes of moisture are an excessive water content in the mortar when the walls were built, poorly filled joints, faulty flashings, especially under parapet copings, leaks in rain conductors or gutters, poorly built cornices, and inadequate caulking around door and window frames. The tops of projecting brick courses should be protected by a cement wash or by lead or copper flashings. High parapet walls are often a source of trouble as they are subjected to the weather from two sides. Where not protected by flashings, it is advisable to plaster the backs of parapet walls or paint them with waterproof paint.

Attempts have been made to develop mortars free of soluble salts. Some progress has been made, but there does not appear to be any complete protection against efflorescence. Dry walls result only from good workmanship and design.

PLASTERING

FURRING AND GROUNDS

General Procedure.—Plastering consists in the application of a plastic mortar, called plaster. The plaster may be applied directly to the masonry wall or to wood, gypsum, or metal lathing. Lathing allows part of the mortar to be pushed through and fold over on the inner face, thus forming a key which holds the plaster in position. Sheets composed of layers of fibrous felt and gypsum plaster, perforated or plain, may also be used as bases for plastering.

Furring.—On masonry walls lathing is usually attached to vertical strips of wood, called furring strips, that are 1 in. thick by 2 in. wide and are set 12 or 16 in. on centers. Small structural members, such as **I**'s, channels, rods, and **V**'s of rolled or pressed metal, may be used. The furring provides a clear space between the plaster and the wall, thus insuring a dry plaster surface. In the case of frame buildings, furring is used when the supports, such as the under sides of joists, are unevenly spaced, or the surfaces are too wide to take the plaster properly.

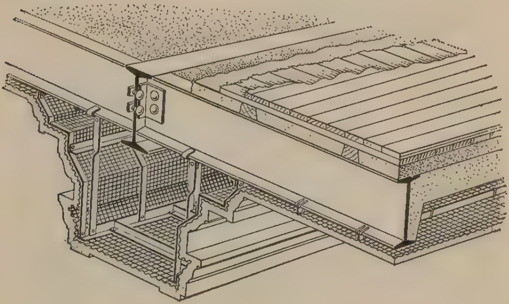


Fig. 1

Metal Furring.—Where elaborate architectural features, such as ornamental surfaces for cornices, beams, and ceilings, are desired, they are formed of a construction of light angles and bars called metal furring. This furring is secured to the frame of the building and is covered with metal lath and plaster. The metal furring should be designed to support the plaster as well as to brace it so that it will be rigid. The furring members should be spaced so as to take metal lath of stock widths. A construction of this kind is shown in Fig. 1.

The metal lath is stretched upon the furring and fastened to it by means of No. 16 or 18 galvanized lacing wire. The illustration indicates the method of furring for a false beam, in which the furring is fastened to the floor beams above.

Grounds.—Wooden grounds should be set around all openings to take the door and window trim, and where needed for bases, wainscotings, picture moldings, etc. The grounds should be put up solidly, straight, and true, and the lathing and plastering should be brought up to them. The thickness of grounds varies with the kind of plastering that is to be applied. For three-coat, lime-plaster work on wooden lath, a $\frac{7}{8}$-in. ground should be used. For two-coat work laid directly upon brick or hollow tile and for gypsum plasters on metal lath, a $\frac{5}{8}$-in. ground should be used. For $\frac{1}{4}$-in. gypsum lath, grounds $\frac{3}{4}$-in. thick are used.

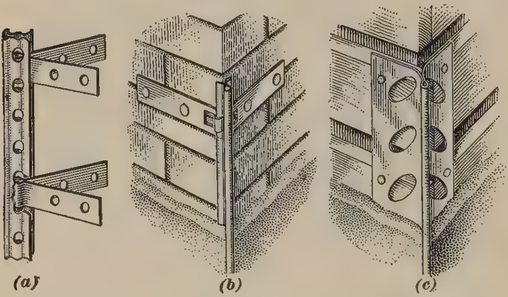


Fig. 2

Corner Beads and Base Screeds.—In good work it is customary to reinforce all corners and angles with metal corner beads, which are secured to the studding or to brick or metal surfaces in a suitable manner and are buried in the plaster with the exception of a narrow fillet at the corner. In Fig. 2 are shown examples of such beads. In (*a*) is a corner bead with adjustable nailing cleats which can be moved up or down

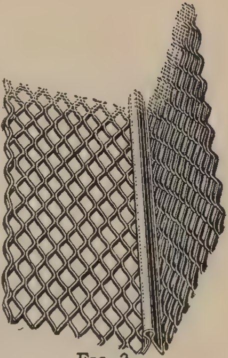


FIG. 3

and secured where the nails will hold the best. A bead is shown nailed to a brick wall in (*b*) and to wooden lathing in (*c*). Similar beads having a metal flange on each side are made for internal angles as shown in Fig. 3.

In Fig. 4 is shown a metal base-screed that is used between a cement or terrazzo base and a plastered wall. The screed edge for the base is shown at *a*, and the screed for the plaster is at *b*. At *c* are holes through which nails can be driven to hold the screed to studs, or by which the screeds may be wired to metal lath. The screed in Fig. 5 is used when the adjoining surfaces are

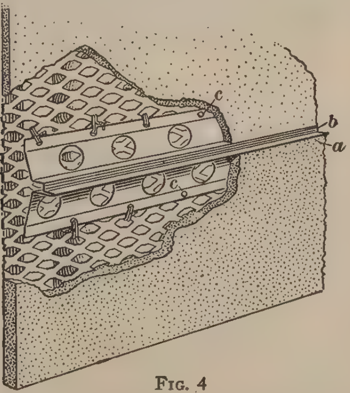


FIG. 4

at the same level, as with a wainscot of Keene's cement and a plastered wall above.

LATHING

Wooden Lath.—Lath made of pine, spruce, or hemlock should be straight-grained, well-seasoned, free from sap and rot, and clear of shakes and large or loose knots. Also, to prevent the subsequent discoloration of the plaster, it should be free from live knots and resinous pockets. The regular size of a lath strip is $\frac{1}{4}$ in. × $1\frac{1}{2}$ in. × 4 ft., the length regulating the spacing of the furring strips, studs, and joists.

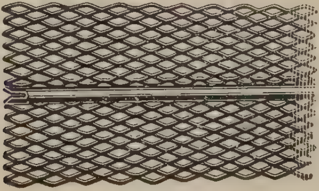


Fig. 5

In frame buildings the lath is attached directly to the studs forming the framing of the walls and partitions. The ceiling lath may be nailed directly to the under edges of the joists or it may be attached to cross-furring, which consists of 1″×2″ strips of wood, nailed at right angles to the joists and set 12 or 16 in on centers. Wooden lath are sold in bundles of 100; and 1,000 laths will cover about 570 sq. ft. of surface. Wooden lath are used occasionally, having been displaced by metal and gypsum lath.

Metal Lath.—Metal lath is made of wires woven together in a square or a triangular mesh, of expanded metal, or of perforated sheet metal. Wire-mesh lath is made of 18- to 22-gage wire with about 2 or $2\frac{1}{2}$ meshes to the inch. It is made in rolls 150 ft. in length and 36 in. in width. It is sometimes stiffened by means of V-shaped bars, as shown in Fig. 6. The lath is coated with asphaltum, painted, galvanized, or japanned to prevent corrosion. It is secured to wooden studs by means of staples or nails, and to iron furring by means of No. 18 annealed steel wire. In Fig. 6 (*a*) is shown the back of the lath, partly plastered; and in (*b*) is shown the front, partly plastered.

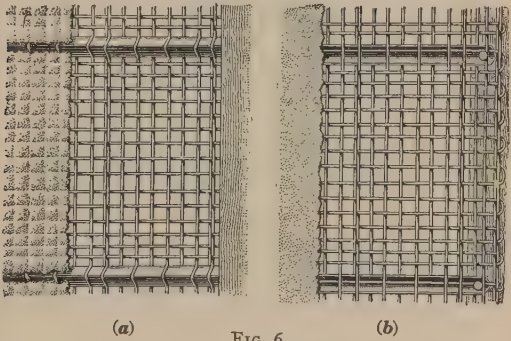
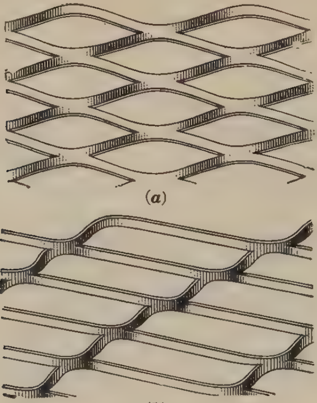


FIG. 6

Expanded-metal lath is formed by cutting slits in a sheet of metal and stretching it apart into a shape somewhat like that shown in Fig. 7 (*a*) or (*b*). This process forms stiff sheets of lathing that require no stretching when placed on the wall. The lath is fastened to the wooden studs or furring with staples; and to metal furring with wire. The lath in Fig. 7 (*a*) has a fine mesh and is used for interior work, while that shown in (*b*) has a coarser mesh and is used for exterior work or stucco. If desired, expanded-metal lath may be formed with ribs, as in Fig. 8.

A lath stamped out of sheet steel is shown in Fig. 9. This sheet is not expanded, but openings are formed in it to allow the mortar to reach the back of the lath. Sheet-metal lath is usually formed with ribs, as shown, which stiffen the sheet and serve as furring to keep the lath a little distance away from the supports, thus allowing the lath to be entirely covered with the mortar.


(a)

(b)

FIG. 7

Gypsum Lath.—Gypsum lath, plaster lath, and other names are applied to sheets consisting of a core of gypsum encased in

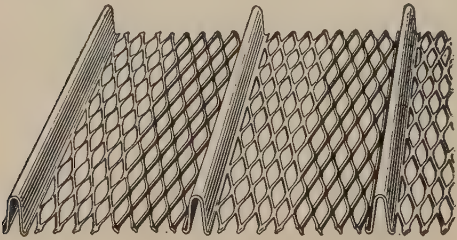


FIG. 8

long-fibered paper. Sheets usually are 16″×32″ and 16″×48″, and $\frac{3}{8}$″ thick. The sheets may present an unbroken surface, or there may be perforations which permit the mortar to be pressed through to form a key. These sheets may be cut with a saw. Gypsum lath is used to take the place of the lath and the scratch coat of plaster, or sometimes of the lath and the scratch and brown coats. The sheets of lath are nailed directly to the furring, studding, etc., by means of smooth wire nails $1\frac{3}{4}$ in. long, and the edges of the sheets are set about $\frac{1}{4}$ in. apart.

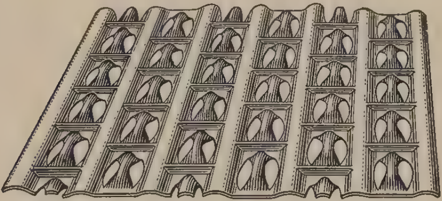


FIG. 9

PLASTER

Plastering Materials.—The composition of plastering mortar depends on the nature of the surface to be coated, the order in which the layers are applied, and the desired finish. For ordinary work the materials are lime paste, sand, hair, gypsum, and plaster of Paris.

Hair or fiber is employed to bind the paste together and to render it more tenacious. Cattle or goat hair is used for this purpose, the latter being considered the better. Other binding materials are frequently used in making plaster, such as Manila fiber, jute, and asbestos.

Gypsum is an hydrated sulfate of calcium which occurs in nature in large deposits in many places. When mined, it is a soft rock, and it is prepared for use by heating, which drives off part of the water. In setting, the gypsum simply takes up water from the mortar, forming the same basic rock again. Gypsum is sold in various forms for use as gypsum plaster or hard wall plaster. Gypsum plasters require no soaking or slaking but are ready for use when mixed with sand. Gypsum is slightly soluble in water, and therefore is unsuited for exterior work.

Plaster of Paris is simply refined gypsum. While unfit for exterior use, it is valuable for interior cornice molds and enrichments, and is also used in several plaster finishes. The great value of plaster of Paris is that paste made from it sets rapidly and acquires full strength in a few hours. It expands in setting, making it a good material for filling chinks and holes in repair work.

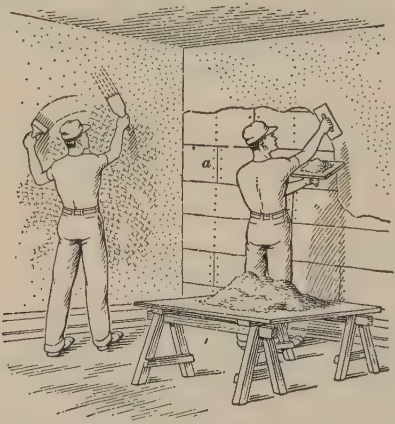


FIG. 10

Placing Gypsum Lath.—Gypsum lath are nailed in place in parallel rows, the edges and ends being kept about $\frac{1}{4}$ in. apart. Nails should be $1\frac{1}{8}''$ long with $\frac{3}{8}''$ flat heads, spaced approximately 4″ apart with not less than four nails per stud.

Gypsum lath cuts cleanly and is easily fitted around openings. Continuous joints should not occur on any support, and joints should be made as shown in Fig. 10 at *a*. Otherwise, cracks will be likely to disfigure the plaster.

Mixing Lime Plaster.—Lime plaster should be mixed in tight boxes. The lime paste is mixed with 2 parts of sand, and the hair or fiber is added. For the first coat of lime plaster, 1½ bu. of hair are used for 200 lb. of lime. This mass, which is known as rough stuff, is stacked and allowed to stand 7 to 10 da. before use.

Mixing Gypsum Plaster.—Gypsum plaster comes on the job ready to mix with sand, although some forms are already sanded. As gypsum plasters set like cement, the materials should be mixed fresh every hour or two, only enough water being added to give the plaster the proper consistency. No plaster that has set partially should be used. It is important that the directions of the manufacturer be followed closely to insure good work.

Scratch Coat.—Plastering is generally done in three coats on wood or metal lath, and in two coats on hollow tile, concrete, and brick surfaces and on plaster lath. Some variation will be necessary on account of the different materials, bases, etc. For three-coat work with lime plaster, the rough stuff is taken in batches from the pile, tempered to the proper degree of firmness, shoveled into hods, carried to the rooms, and deposited on the board *f*, Fig. 10. A quantity of plaster is placed on the hawk *g* by means of the trowel *h*, and from there is applied to the lathing and spread firmly and evenly over the surface with the trowel.

The mortar should be tough, hold together well, and yet be soft enough to be pressed between the lath and bulge out behind, forming the key. The thickness of the layer should be fully ¼ in. After the coat has somewhat hardened, it is scratched over diagonally with wooden comb-like tools *i*; from this fact, the first layer is often called the scratch coat. The grooves formed fulfil the same function as the spaces between the strips of lath. to allow a good key for the subsequent layer.

Brown Coat.—The second coat of plaster, consisting of a mixture of 1 part of lime paste to about 3 parts of sand and the proper amount of hair, is applied when the scratch coat has become dry; the second layer is called the brown, or floated coat, because its surface is worked over by means of board-shaped trowels, called floats. It is also known as the straightening coat, since all the surfaces are straightened and made true. This is effected by first forming a series of plaster bands, called screeds, 5 or 6 in. wide, on the surface to be floated as in Fig. 11. The surfaces adjacent to the angles are carefully plumbed up from the plaster ground e but are kept about $\frac{1}{8}$ in. back from the face, to allow for the finishing coat. The vertical screeds f are formed by means of the straightedge g. Similar screeds h are formed along the ceiling angles; these screeds are made straight, and coincide with those at the

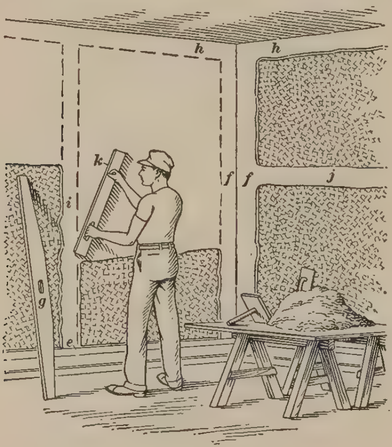


FIG. 11

opposite angles. Intermediate vertical and horizontal screeds *i* and *j* are then formed between the screeds adjacent to the ceiling and the plaster grounds; these are usually placed from 4 to 8 ft. apart, and are gaged to line by means of a straightedge. The screeds thus form a system of framing that has been reduced to a true plane; the panels are then filled in flush with the screeds, and the surface is firmly rubbed down with a two-handed float *k* called a derby.

The surface is then worked over with a wooden hand float, the coat being firmly compacted by incessant rubbing; when the coat becomes dry during the process, it is moistened with water, applied with a wide brush. A close, firm layer can be obtained only by the thorough, laborious operation of pressing and rubbing the particles of the mortar together. The ceiling surfaces are treated in a similar manner, and the screeds are carefully leveled so as to secure true and level planes. In order to form a key for the subsequent coat, the surfaces are scratched over with a broom.

Running Cornices.—Where cornices are desired, they are run before the finishing coat is put on; where the molded surfaces do not project more than 2 in., the body may be of coarse stuff, but where the projection is in excess of this, a furring of brackets and lath, made to conform to the general profile, should be arranged for its support. Cornice molds are made of galvanized iron, or zinc, attached to a wooden back, which in turn is secured to guide and brace strips. Longitudinal strips are attached to the wall either by nails or a layer of plaster of Paris, and on this the mold guide runs. The coarse stuff is made to conform to the approximate profile with a muffled mold, that is, by forming a layer of plaster of Paris along the edge of the mold, about $\frac{1}{8}$ in. in thickness; or an extended profile can be cut out of zinc and attached, temporarily, to the mold. When the coarse stuff has been properly profiled, the surface is coated with gaged stuff and carefully worked over with the correct mold, until an exact and perfect finish is obtained. The internal and external angles cannot be finished by means of the molds, but require to be carefully molded and mitered by hand using jointing tools.

Finishing Coat.—The third, or finishing coat, is designated by various terms, such as skim coat, white coat, putty coat, sand finish, etc. In all cases the material is applied to the wall in the form of a stiff paste, by means of a steel trowel, and is spread uniformly over the surface to a thickness of about $\frac{1}{8}$ in.

The skim coat is made of lime putty and beach sand that has been washed. Lime putty is slaked lime that has been run through a sieve into a tight box and allowed to stand for 10 to 14 da. The skim coat is put on with a trowel, floated down, and then polished to a glazed surface with a trowel, the surface being kept moist by water applied with a brush.

The white coat consists of gaged stuff made of lime putty, mixed with plaster of Paris to the proper consistency, smoothed and polished with the steel trowel; as this material sets rapidly, care must be taken to observe that the second coat is well dried, otherwise the unequal shrinkage will cause hair cracks to occur all over the finishing coat.

A sand finish is produced by applying a coat consisting of lime putty mixed with more sand than is used in the skim finish, and floating it with a soft pine or cork float. The coarser the sand is, the rougher will be the surface of the wall.

The space between the plaster grounds and the floor is usually finished with a scratch and a brown coat of plaster, so as to prevent air-currents entering the room from the channels between the furring strips; in cheap work this filling is omitted, the space being covered by the skirting or base.

Two-Coat Work.—An economical form of plastering is known as two-coat work. The first coat forms the key, but is not scratched and allowed to dry. Instead, the brown coat is applied immediately, worked into the scratch coat, and floated to take the second or finishing coat.

Applying Gypsum Plaster.—Gypsum plasters are applied in practically the same manner as lime plasters, and may be either two-coat or three-coat work. When the plaster is applied to stone, brick, or tile, the surfaces should be sprinkled before putting on the coat. Wooden lathing should also be well moistened, so that the laths will swell before, and not after, the plaster has begun to set. The makers of gypsum plasters recommend that the strips of wooden lath be spaced ¼ in. apart, and that ¾-in. grounds be used. The finishing coat is applied when the base coats are thoroughly dry, and may be of lime, gaging plaster, and sand, as already described for lime plasters, or of gypsum finishing plaster.

Gypsum plasters have points of superiority. Being machine-mixed, they are uniform in proportions of ingredients, quality, and strength. They also are much harder and more tenacious, and resist fire and water better than lime plasters. The small quantity of water used in mixing them enables them to dry out much more rapidly. They are not injured by frost after they have begun to set, but should be protected from it for the first 36 hr. after being put on the wall. Heat and moisture are not readily transmitted by gypsum plasters, and, being more dense than lime plasters, they do not absorb noxious gases nor permit the entrance of disease germs.

Ornamental Plastering.—Ornamental plastering embraces all cornice work, centerpieces, brackets, ornamental moldings, panel ornaments, etc. This work is generally cast and is secured in place by plaster of Paris.

Keene's Cement.—Keene's cement is a product formed by calcining plaster of Paris that has been saturated with a solution of alum. When a highly polished and particularly hard white finish is desired, as in imitation tile wainscots in kitchens, bathrooms, etc., Keene's cement is used. It is generally applied on a base of cement plaster on metal lath. Where a tile effect is desired, the surface is ruled off while soft with vertical and horizontal joints in tile size.

Caen Stone Finish.—The finish known as Caen stone may be applied as the finishing coat of lime or gypsum plaster. Caen stone, a natural stone found in France, is ground to a powder as a base for this finish, and it gives the plaster the proper color and texture when mixed with the sand and finishing material. When the surface is dry, it is sand-papered smooth to represent a sand-rubbed surface, or is combed with a tool to resemble a tooled surface. Joints are usually cut in the finishing coat and are filled with white mortar. producing the effect of stone blocks set in white mortar.

Outside Plastering.—Outside plastering, or stucco, should always be two-coat work. When stucco is to be applied on hollow tiles or brickwork, the material to be covered should be thoroughly wet. The scratch coat should be at least $\frac{1}{2}$ in. thick and composed of 1 part of portland cement, 3 parts of sand, and not more than 10% by volume of lime putty or hydrated lime. The first coat should be thoroughly pressed on, so as to form a good key, and well scratched before it sets. The second coat should be $\frac{1}{4}$ in. thick, composed of 1 part of

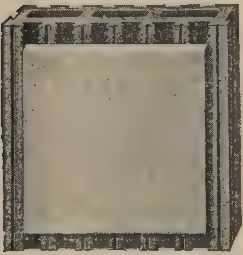


FIG. 12

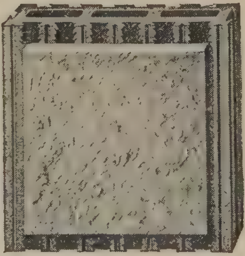


FIG. 13

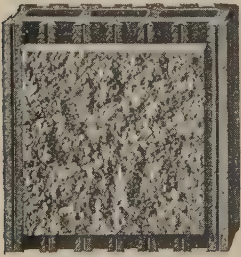


FIG. 14

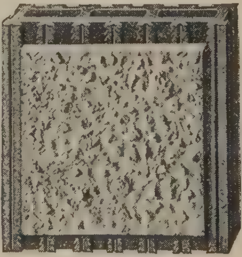


FIG. 15

portland cement and 2 parts of sand, and colored as desired with yellow ochre, lampblack, or mineral pigment. For a sand finish, as shown in Fig. 12, a float is used covered with burlap. A pleasing surface, like that shown in Fig. 13, is obtained by stippling with a sponge full of thin cement.

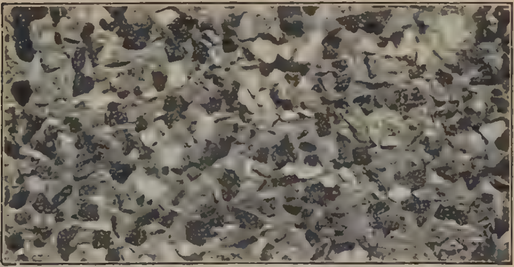


FIG. 16

The finishes shown in Figs. 14 and 15 show different effects caused by casting or throwing the second coat mixed with pebbles against the scratch coat. Figs. 16 and 17 show surfaces formed of marble chips and broken stone tamped into

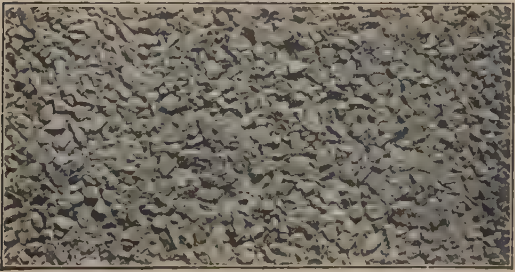


FIG. 17

the wet mortar with the float. Fig. 18 shows small pebbles pressed into the surface of the finishing coat of plaster.

Whitewashing.—Whitewashing is often included in the plasterer's specifications. Common whitewash is made by slaking fresh lime and adding enough water to make a thin paste. It is applied to walls and other surfaces with a brush. Whitewash will adhere best to rough and porous surfaces. For good work, two coats should be put on. By using 2 lb. of sulfate of zinc and 1 lb. of salt to each ½ bu. of lime, the whitewash will be rendered much harder and will be prevented from cracking. It durability, especially for outside work, may be increased by mixing 1 pt. of linseed oil with each 2 gal. of whitewash. Whitewash is a very useful agent for preventing decay of wood, and is valuable from a sanitary point of view in buildings of wood, stone, or brick.

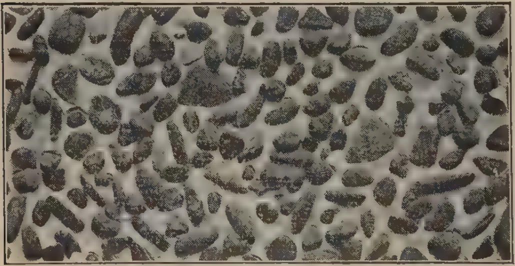


FIG. 18

CARPENTRY AND MILLWORK

WOODS USED IN BUILDING

DESCRIPTION OF WOODS

White, or Northern, pine is a light, soft, straight-grained wood that is used in building, principally as a finishing material when work is to be painted. Its power of holding glue renders it valuable to the joiner. The tree is common in the Northern part of the United States and Canada.

Long-leaf pine, also known as hard or Georgia pine, has a well-marked grain, on account of which it is sometimes used as a finishing material. The wood is heavy, hard, strong, and under proper conditions, very durable, but decays rapidly in damp places. On account of its resinous nature it does not take paint well. Georgia pine is often confused with Carolina, yellow, or Southern pine, which is greatly inferior to it.

Short-leaf pine, or North Carolina pine, is neither so strong nor so durable as long-leaf pine. In appearance it is somewhat lighter in color than long-leaf pine, the fiber is softer and contains less resin than that of long-leaf pine.

Sugar pine grows on the Pacific coast. The wood is straight-grained and of a compact structure, is soft, easily worked, and resembles white pine. It is used in carpentry and for interior finish.

Oregon pine, sometimes called Douglas fir, while really belonging to the spruce family, so closely resembles pine that it is so called. While nearly as strong as Georgia pine, it is much lighter in weight, and more easily worked. Owing to the long lengths in which it can be obtained, it is in demand for flagstaffs and long framing.

Black spruce, growing in the Northeastern states and Canada, is light in weight, reddish in color, and though easy to work, is very tough in fiber. It is largely used for submerged cribs and piles, as it not only preserves well under water, but also resists the destructive action of parasitic crustacea.

White spruce, scarcely distinguishable from black, is largely used throughout the Eastern states for all classes of lathing, framing, and flooring.

Hemlock is like spruce in appearance, but much inferior in quality, is brittle, splits easily, and liable to be shaky. It is only used as a cheap, rough framing timber.

White cedar, a soft, light, fine-grained, and very durable wood, lacking strength and toughness, is much used for boat-building, cigar-box manufacture, shingles, and tanks.

Red cedar, a smaller tree than white cedar, similar to it in texture but more compact and durable, is of a reddish-brown color, and possesses a strong, pungent odor, which repels moths and other insects, making it extremely valuable as shelving for closets, and linings for chests and trunks.

Cypress, a wood very similar to cedar, growing in the Southern part of the United States, is one of the most durable woods and well adapted for outside or inside work. Special care must be taken in seasoning it, as it tends to sliver and become shaky if forced in the drying.

Redwood, the name given to one of the species of giant trees of California, grows to a height of from 200 to 300 ft., its trunk being bare and branchless for one-third of its height. The color is a dull red, and the wood, resembling pine, is used in the West the same as pine is in the East. As an interior finish it is capable of taking a high polish, and its color improves with age.

White oak is the hardest of the American oaks, and grows in abundance throughout the eastern half of the United States. The wood, heavy, hard, cross-grained, strong, and of a light yellowish-brown color, is used where strength and durability are required, as in cooperage and boat making, and is especially prized as a material for cabinetwork, when the log is quarter-sawed. In first-class work, it is usually cut into veneers $\frac{3}{16}$ in. thick, which are laid on cores of white pine or chestnut. The silver grain and the high polish that the wood is capable of receiving make it one of the most beautiful used for interior finish and floors, as well as for furniture and interior fittings. It is adapted to several finishes.

Red oak is darker and redder, coarser, more brittle, and of a more porous texture than white oak. It is much used for the interior finish in buildings.

White ash, the wood of a large tree growing in the colder portions of the United States, is heavy, hard, very elastic, and exceedingly tough. Its grain is coarse, and very much like bastard-sawed oak in appearance. It is used for interior trim; and when properly filled can be brought to a high polish. Ash is sometimes used for cabinetwork, but its tendency to decay and become brittle renders it unfit for structural work. Black ash has a brown, cedar-like appearance.

Locust is one of the largest forest trees in the United States, and furnishes a wood that is as hard as white oak. Its principal use is in exposed places where great durability is required; also where it comes in contact with the ground, as in posts. It is also very durable in damp places. Its hardness increases with age.

Black walnut is heavy, hard, porous, and of a purplish color, marked by a beautiful wavy grain. Strong, durable, and not subject to the attacks of insects, it is used generally for small cabinetwork, gun stocks, and interior decoration. The knotted roots of the tree furnish material with a curly grain, called burl, which is cut up into veneers.

Cherry is moderately heavy, hard, very durable, and has a close, fine grain. It is susceptible of a high polish, and is much used for fine interior trim and cabinetwork. Cherry stained black to imitate ebony cannot be detected, except by scraping the polished surface. It is largely used for piano cases, furniture, etc.

Birch strongly resembles cherry in texture, and in some species in color also. Black or cherry birch furnishes the best lumber, but is not as durable as ordinary birch, and is more affected by atmospheric influence.

Sugar, or hard maple is a light-colored, fine-grained, strong, and heavy wood. The medullary rays are small and distinct, giving a silver grain to the quarter-cut lumber. It is used for flooring and interior trim, but for fine work it is used as veneer. Curly maple is maple in which the waviness of the grain is similar to that obtained from the roots of the walnut tree. Bird's-eye maple is produced in old trees by the circular inflection of the fibers. Though both the curly maple and the bird's-eye are practically distorted fibers, and reduce the strength of the wood, they are highly prized in the cabinet-maker's art.

Chestnut is comparatively soft, close-grained, and, though very brittle, is exceedingly durable when exposed to the weather. American chestnut has been killed by a blight.

Poplar, or whitewood, a lumber of the tulip tree, is a large straight forest tree, abundant in the eastern part of the United States. It is light, soft, very brittle, and shrinks excessively in drying. In color it varies from white to pale yellow. The cheapness and ease of working poplar cause it to be largely used for the cheaper grades of carpentry and joinery work, but it warps and twists exceedingly in even slight atmospheric changes.

Buttonwood, also called sycamore, is the wood of a tree generally known as the plane tree. It is heavy, hard, of a light-brown color, and very brittle. The grain is fine, close, and susceptible of a high polish. It is very hard to work, liable to decay, and has a strong tendency to warp and twist under variations of temperature. On this account it is best used for veneered work.

Basswood is the name given to the American linden tree. In general appearance it strongly resembles pine, but is much more flexible. It has a great tendency to warp, and will shrink both across and parallel to the grain. It is much used for curved panels.

Mahogany is a native tree of the West Indies and Central America. The color, grain, and hardness of the wood vary considerably according to its age and locality of growth. It is used for the highest grades of joiner work. The straight-grained varieties do not warp or shrink materially with atmospheric changes, while the cross-grained varieties warp and twist to a remarkable extent, and can, therefore, be used to advantage only when veneered upon some more reliable wood. The soft and inferior grades from Honduras and Mexico are called baywood to distinguish them from the rich deep-red San Domingo or Spanish mahogany. Prima Vera or white mahogany is of a creamy color, very much like the baywood in texture, and makes a beautiful finish for fine work.

Rosewood is a heavy, hard, and brittle wood, from several trees native to the tropical countries. It has a beautiful grain, alternating in dark brown and red stripings, which when well polished makes the surface one of the handsomest products of the vegetable world. As a veneer, it is applied to all kinds of cabinet, furniture, and joinery work where richness and durability are required, regardless of expense.

Ebony, a dark, almost jet-black wood, native to the East Indies and parts of Africa, is heavy, strong, and exceedingly hard, with an almost solid annual growth. It takes a high polish, and is used in cabinetwork.

Sweet- or red-gum, a tree of large growth, is very plentiful in the Central and Eastern States. It is soft in texture, but strong and tough, and strongly resembles light-colored walnut. It presents a very handsome appearance when selected and well finished, but has a tendency to warp and shrink, which makes it unreliable, unless used in veneered work. It is largely used for fine interior trim, and cabinetwork.

RELATIVE HARDNESS OF AMERICAN WOODS

Woods may be divided into four classes in considering their hardness, using the term hardness in its literal sense. The very hard woods are hickory, hard maple and the best qualities of oak. The hard woods are oak, cherry, ash, birch, black walnut, and sycamore. The medium hard woods are the Southern and Western pines, Douglas fir, and sweet gum. The soft woods are white pine, spruce, hemlock, cypress, redwood, poplar and chestnut.

SHRINKAGE OF WOODS

When seasoning in the open air, boards shrink very little lengthwise of the grain, but shrink in width from 3% to 10%. The approximate shrinkage in width for different woods is given in the accompanying table.

TABLE OF SHRINKAGE OF WOODS

Kind of Wood	Per Cent of Shrinkage	Kind of Wood	Per Cent of Shrinkage	Kind of Wood	Per Cent of Shrinkage
White pine	3	Ash	5	Sycamore	5
Spruce	3	Elm	5	Birch	6
Hemlock	3	Walnut	5	Chestnut	6
Cypress	3	Poplar	5	Hickory	6 to 10
Long-leaf pine	4	Maple	5	Oak	6 to 10
Short-leaf pine	4				

QUALITIES OF TIMBER

The best timber is obtained from mature trees, the fibers of which have become compact and firm, both by the drying up of the sap and by the compressive action of the bark. There is a great difference both in appearance and strength between the heart-wood, or duramen, and the sap-wood, or alburnum; in the former, the fibers are firm and dense, and possess a deep color; in the latter, they are open, porous, and filled with sap, and are usually of a pale color. The heart-wood is much stronger, and less liable to decay and to the attacks of insects, than sap-wood.

The medullary rays consist of vertical layers or sheets, radiating from the center, and connecting the pith with the bark. They are not, however, continuous, but are broken by the interweaving of the fibers. Those rays extending from the pith to the bark are called primary rays; those extending through only a portion of the stem are called secondary rays. The medullary rays are prominent in oak, beech, and sycamore, but are not so well defined in birch, chestnut, and maple. It is the presence of these medullary rays, sometimes called silver grain, that gives so much beauty to quartered oak.

Figure 1 represents a section of an oak or ash tree, the coarse texture formed of the large sap vessels being shown at *a*, the closer texture at *b*, the bark at *c*, the primary medullary rays at *i*, and the secondary ones at *j*.

Selecting the Stock.—In good lumber for building purposes, the heart-wood should be sound and mature, the sap-wood, or layers next the bark, being entirely removed. The wood should appear uniform in texture, straight in fiber, be free from large or loose knots, flaws, shakes, or any kind of blemish. When the rings are close and narrow, they denote a slowness of growth, and are usually signs of strength. When freshly cut, the wood should smell sweet; a disagreeable smell is a sign of decay. The surface, when sawed, should not appear woolly, but be firm and bright, and it should not be clammy and choke the saw. When planed, the wood should have a silky appearance; the shavings should come off like ribbons and stand twisting around the fingers. When the wood appears dull and chalky, and the shavings are brittle and friable, it is not first-class stock. Good lumber should be uniform in color; when blotchy or discolored it signifies a diseased condition.

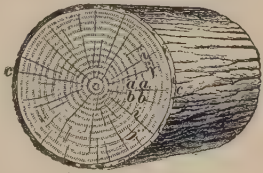


FIG. 1

Imperfections.—There are various defects in timber, which may be caused either by the nature of the soil in which it grew or by accidents due to storms, etc.

Heart shakes are cracks or partings of the fibers, radiating from the center of the tree. They are common in nearly all classes of timber, and are caused by the shrinkage of the inner layers incidental to loss of vitality; the cracks are wider toward the heart.

Star shakes are cracks radiating from the center, but are wider toward the bark; they are caused by the rapid drying of young timber while it is full of sap.

Cup shakes are curved splits that separate the layers, and are caused by severe wind storms.

Rind galls are curved swellings, caused generally by resinous layers forming over a wound where a branch has been broken off.

Foxiness is a yellow or red coloring, signifying the early stages of decay.

Dry rot is a fungus growth, and can be discovered by a black-and-blue tinge; the end wood is crumbly and crisp. Timber thus affected is of no permanent value, as the rot continues until the fiber becomes powder.

Twisted fibers are caused by the twisting tendency of winds blowing generally in one direction; such timber possesses little strength, owing to the oblique direction of the fibers.

Knots are either stubs of branches or the gnarly growth formed where the branches are looped off. Knots may be small and sound, in which condition they are not objectionable, or they may be large and loose; if large, the strength of the timber is very much reduced, and, if loose or dark in color, they will ultimately fall out, loose knots being the stubs of dead branches.

QUARTER AND BASTARD SAWING

The term quarter sawed signifies that the log is cut into quarters before being reduced to boards, while the term bastard sawed denotes that all the saw cuts are parallel to the squared side of the log. In genuine quarter sawing (also called rift sawing) the cuts should be as nearly as possible at right angles with the circles of growth, or annual rings, or parallel with the medullary rays *a*, as shown in Fig. 2; while in bastard sawing, the cuts are nearly parallel with the annual rings and expose the edges of the medullary rays *a* and the face of the annual rings, as shown at b' and c' in Fig. 3. The advantages in quarter sawing material having well-defined medullary rays are that it wears better, shrinks less, and the silver grain presents a very fine effect.

Fig. 4 illustrates four methods of cutting the boards from the "quarters." The tree is first quartered by cutting it on lines *ab* and *cd*, after which the quarters may be reduced to boards by any of the methods shown. The best results are secured by the method shown between *a* and *c*, as the saw cuts are nearly on radial lines, and the full face of the silver grain will be exhibited. The section between *c* and *b* shows the next best method; fewer triangular strips are formed, but the boards will not present as rich an effect, as many of the medullary rays are cut obliquely. The result of cutting the section between *a* and *d*, while economical in material, will not give as good results as the two former methods. Where thick material is desired, the system of cutting shown on the section between *d* and *b* is adopted, the cuts being made in the order in which they are marked.

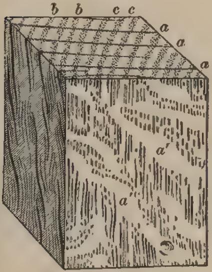


FIG. 2

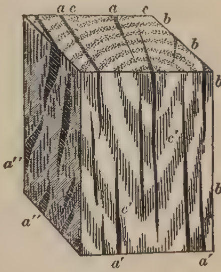


FIG. 3

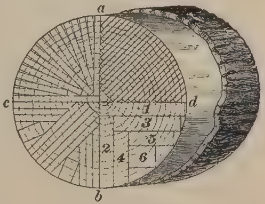


FIG. 4

As before stated, the best effects are produced when the saw cuts come parallel, or nearly so, with the medullary rays: this is shown in Fig. 2. These rays on the end section are marked *a*, and are seen to cross the annual rings *b* and *c* at nearly right angles, so that the edges of these rings are exposed on the face, and through them the silver grain *a′* emerges

The value of quarter sawing does not consist merely in exposing the beautiful figuring of the material, but it is found that the quartered material shrinks less than one-quarter as much in width as the bastard-sawed stock. This is an invaluable virtue, which the joiner and cabinetmaker are not slow to appreciate. Quarter-sawed stock is also less sensitive to changes of temperature, and when once thoroughly seasoned and well put together, it makes an admirable finish both for interior treatment and furniture, and its beauty is greatly enhanced with age.

WOOD FRAMING

BALLOON FRAMING

Definition.—In the balloon system of framing, timbers of small section are used to construct a light, skeleton frame, whose rigidity depends on a covering of $\frac{7}{8}$-in. boarding nailed diagonally to the studding. This is the distinguishing feature of balloon framing compared with braced framing, in which the rigidity depends on a well-arranged system of mortise-and-tenon joints and diagonal bracing, irrespective of covering. A practical application of balloon framing is shown in Fig. 1 which is an isometric sketch of part of a building during erection.

Sill.—After the wall *a* is completed, the 4″×8″ sill *b* should be laid in a bed of mortar, tamped, and carefully leveled, as from it all heights are measured. The edge should be kept back from the face of the wall, so that the outside boarding or sheathing will be flush with the latter. The sill should also be accurately squared, to obtain satisfactory results. A very simple and practical method of squaring depends on the geometrical principle governing right-angled triangles; namely, the hypotenuse is equal to the square root of the sum of the squares of the other two sides. This principle is illustrated at the near corner of the sill in the figure. Lines are drawn on the top of the sill equidistant from the outer edges, and a nail is driven at their intersection. From this point 6 ft. is measured on one line and 8 ft. on the other, and nails are driven at

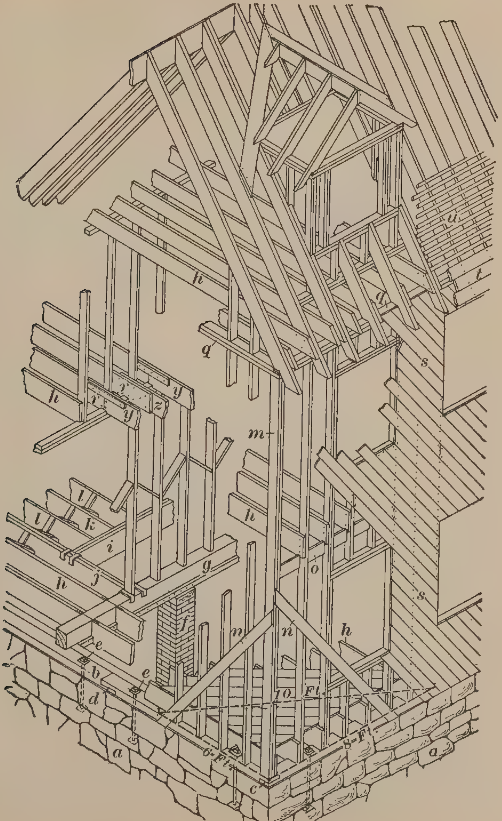


FIG. 1

the points marked. Where the pieces are square to each other, the hypotenuse will measure just 10 ft. Triangles with sides that are multiples of 3, 4, and 5, such as 6, 8, and 10, 9, 12, and 15, etc., may be used also.

The sill is halved and spiked at the corners as shown at *c* and where the pieces composing it cannot be obtained in sufficient lengths, the sill is pieced out by means of the beveled splice, as shown at *d*. In exposed situations where high winds are frequent and when the frame is placed over a lower story of masonry, the sill is anchored to the wall by means of anchor bolts. These bolts are from 1 in. to 1½ in. in diameter, and are firmly built into the masonwork of the wall with the thread end projecting above it. Holes are then bored into the sill to fit over these projecting ends, and, after the sill is laid and leveled, it is securely held in place by screwing nuts tight on the ends of the bolts with a washer between each nut and the sill, as shown at *e*.

Girders.—Where the span is so great that the floor joists must have an intermediate support, a masonry wall or else a girder is used, and is placed parallel with the bearing walls. If a girder *g* is used, it is supported at intervals by wooden or iron posts or else by brick piers, as shown at *f*. The girder may be of wood, which is generally used in frame houses, or it may be a steel beam, which is preferable from the fact that it will not shrink. The girder *g* has 2″×4″ strips spiked to the sides to support the ends of the joists.

Joists.—When the sills and girders are in place, the first-floor joists *h* are then set as shown, and are notched down over the girder and sills. Care must be taken not to notch the end of a joist more than about one-sixth of its depth from the bottom or else it may split along the line of bearing. Headers *i* and trimmers *j* should be double the thickness of the joists or, may be formed of two single joists spiked together with the grain reversed. The tail-beams *k* may be supported on strips nailed to the side of the header, in the same manner as they are supported on the girder *g*. They may also be supported by iron hangers or by tusk-and-tenon joints. If the header *i* is more than 4 ft. in length, it should be supported from the trimmer by iron hangers. The trimmer *j* is shown supported on the girder by iron hangers.

The joists should be braced every 5 ft. or 7 ft. with cross bridging, or herring-bone bridging, which consists of 1″×2″ or 2″×3″ strips nailed diagonally between the joists as shown at *l*. The joists are generally 2 in. or 3 in. thick and from 6 in. to 14 in. in depth, and are spaced from 12 in. to 16 in. on centers. They should be spiked to the sides of the studs of walls and partitions where possible. If the carpenter, on looking along the edge of a joist finds that it is curved, or crowned, he should place it with the convex edge uppermost so that when the joist settles it will be level.

Owing to the fact that timber is often sawed scant of its supposed dimensions, it is generally sized, or notched down a fraction of an inch, at the bearings so that when set the tops of a series of joists will be at the same level.

Corner Posts.—Corner posts *m*, which consist of two pieces of timber spiked together, are placed at all corners of the building and where bearing partitions meet the outer walls. If the studding is 4 in. wide, the corner post will be formed of a 4″×6″ stick with a 2″×4″ stud nailed on the long side. These posts are held in place by temporary braces *n*.

Studs and Ribbon.—The outside studs are cut with notches to take the ribbon or ledger board *o*, and are set in place 12 in. or 16 in. on centers and the ribbon is nailed to them. The studs are doubled around all openings. The second tier of joists is set in place, notched over the ribbon and spiked to the sides of the studs. They are sized down on the partition either lapping and being spiked together as at *z*; or with butting joints as at *y* and being spliced together by $\frac{7}{8}$-in. wooden fish-plates. The joists are nailed to the sides of the studs where possible as at *r*.

Plate.—The plate *q*, formed of two 2″×4″ pieces, is spiked down on top of the posts and studs, and is lapped at the corners and elsewhere where necessary. The attic joists, *h* are then put in position, their ends resting on the plate and the partition. The joists act as collar beams tying the bottoms of the rafters to prevent their spreading, and should be firmly spiked to them. Care should be taken that the frame does not get out of plumb, or perpendicular, and it should be well braced until all the sheathing is on and the partitions are set.

Braces.—In some cases, braces *n* are let into the corner posts, sills, and intermediate studs and keep the corners plumb and strengthen the frame.

Partitions.—The supporting partitions are made of 2″×4″, 3″×4″, or 2″×6″ studs of hemlock or spruce, set 12 in. or 16 in. on centers. Where one partition comes immediately above another, it should bear directly upon the cap of the one below, which is made of two partition studs laid flatwise. Studs should be doubled around all openings and openings over 3 ft. wide should have a simple truss formed above them as shown at *a*, Fig. 2. Partitions, if more than 8 ft. in height, should be bridged with pieces of studding as at *b*.

Sheathing.—Before the building is sheathed, the corner posts *m*, Fig. 1, should be carefully replumbed and adjusted by means of a plumb-bob suspended from the wall plate and run down to the sill, when the most accurate adjustment can be made. The sheathing *s* should be placed diagonally at an angle of 45°, and be well nailed to each stud with two or three nails, according to the width of the board. The butt joints should be cut on the center line of the studs. With boarding thus placed, well fitted and nailed, the structure is completely braced in a very simple and effective manner. The outer surface should be covered with a layer of heavy building paper

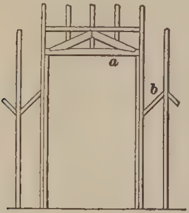


FIG. 2

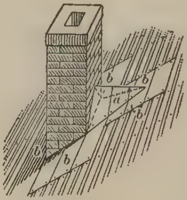


FIG. 3

lapped at the edges and tacked in place. Paper, being of close texture and a non-conductor of heat, makes an excellent covering material, rendering the building warmer in winter and cooler in summer.

Sheathing consists of a cheap kind of lumber, $\frac{7}{8}$ in. thick, but the boards should be dressed to an even thickness. The roof is also covered with sheathing boards, but when tiles, slate, or shingles are used, strips are sometimes nailed horizontally to the rafters as shown at *u* and spaced at a distance apart equal to the distances between nailings of the roofing material. When rafters project beyond the face of the building, they should be covered with sheathing for their full projection as at *t*. Sheathing should be placed on each side of all valleys; for 8 or 10 in. on each side of the ridge and around all chimneys, as at *b*, Fig. 3. At the backs of all chimneys saddles should be formed as shown at *a*, Fig. 3.

Insulation.—Good practice indicates that it is desirable to insulate the exterior walls of a building so as to make the interior warmer in winter and cooler in summer. This insulation may consist of special boards. Types of insulating board are now made that are recommended by the manufacturers as suitable for sheathing purposes. These boards serve the double purpose of enclosing and bracing the frame and also insulating the building against temperature changes.

Boards are made in large sizes, and the joints are fewer than in wood sheathing. Insulation-board sheathing is available in units that are 4 to 8 ft. wide, up to 14 ft. long, and $\frac{25}{32}$ in. thick. Special sheathing boards that are 2 ft. wide and 8 ft. long and are intended to be applied horizontally are also made. It is claimed that a frame building with insulation-board sheathing is fully as rigid as one with wooden sheathing.

Boards known as rigid insulation are used not only on the exterior of the frame but also on the interior, thus forming a double insulation. Thinner boards, which are $\frac{1}{2}$ in. thick, are also used in the form of insulation.

WESTERN FRAME CONSTRUCTION

Definition.—Western frame construction is a term that is applied to a type of framing in which lumber nominally 2 in. thick is used, and in which the supporting studs extend from the top of each tier of joists to the under side of the tier next above, the studs being provided with soles and plates. Each story has its separate studs, joists, and other framing members. This type is used in the western and southern states.

Characteristics.—In the Western type of framing, each story is framed separately. The stud spacing may be different in the two stories, if desired, as the studs do not extend through more than one story. Window and door openings need not have trussed headers over them, as the construction prevents loads from coming on the heads of the windows below.

Example.—An example of Western frame construction is shown in Fig. 4, the general design of the building being similar to that shown in Fig. 1, in which balloon framing was used. The frame rests on a masonry foundation, the sill *a* being a $2'' \times 8''$ piece bolted to the masonry. At *b* is a header against which the joists *c* stop, and at *d* is a doubled joist at the end of the building. This doubled joist takes the place of the header on the side of the building. If the building is too wide for joists to span the distance from wall to wall without intermediate supports, or the use of joists in one length, an intermediate girder is necessary. The girder *e* is built up of two or more 2-in. pieces. The ends of the joists are supported on $2'' \times 4''$ cleats *f* on either side of the girder. Bridging *g* is used to add stiffness to the joists. Over the joists and extending to the outside of the headers, $\frac{7}{8}$-in. rough, or under, flooring *h* is laid diagonally. On this floor is laid a $2'' \times 4''$ sole *i* on which the studs *j* and the posts *k* stand. The corner posts *k* are built up of three $2'' \times 4''$ studs, arranged to furnish nailing for the sheathing on the outside and for lath on the inside of the building. This corner post is similar in design to the posts shown in balloon framing. At the corners of the building braces *l* are built in to stiffen the frame.

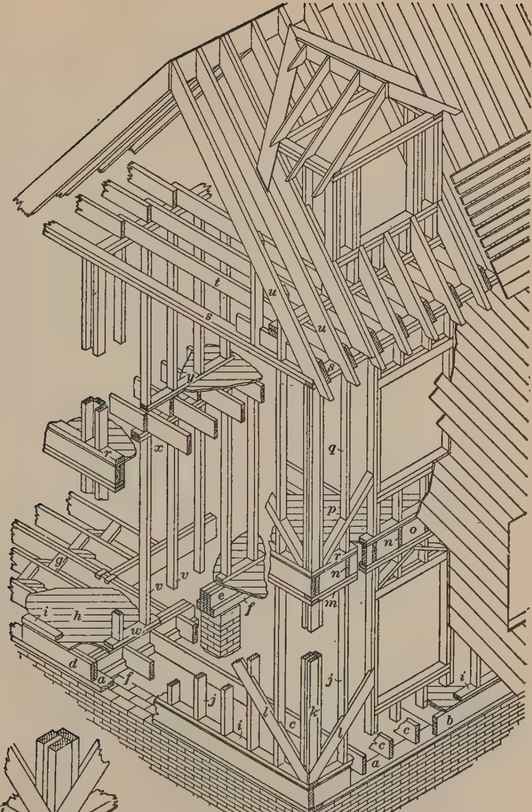


FIG. 4

Another method of framing the second-story joists is similar to that used for the first-story joists, where the ends of the joists are butted into a header. Where this method is used the ends of the joists have only a 2-in. bearing, and should be thoroughly spiked to the header.

Two 2″×4″ pieces are used at *m* as a girt, or plate, on the top of the first-story studs. The second-story joists *n* rest on this girt and extend out to the sheathing. Headers or blocking pieces *o* are built in between the ends of the joists to provide nailing for the flooring *p*, which is laid diagonally across the joists, and extends out to the sheathing as in the first story.

In the second story, the studs *q* rest on a sole *r*, the same as in the first story, and the studs extend to a doubled 2″×4″ plate *s*, which supports the attic joists *t* and the rafters *u*. These attic joists and rafters are 2 in.×6 in., although with wide spans it will be necessary to use larger sizes.

Fig. 4 shows the framing necessary to provide for window openings, gables, stair openings, etc. In a general way the same method of jointing is followed as with the balloon frame, all of the joints being butt or lap joints. The studs are doubled at each side of the door and window openings, and the heads and rough sills of the windows are doubled, as well as the door heads.

BRACED-FRAME CONSTRUCTION

Definition.—The braced-frame method of construction is one in which the principal parts of the frame are joined together with mortise-and-tenon joints, and in which the angles are braced rigidly. The whole frame, consequently, is stiff and secure in itself before the sheathing is applied. A portion of a building having a braced frame is shown in Fig. 5. This building is the same in plan as the one shown for balloon frame, Fig. 1, and Western frame, Fig. 4.

This type of frame was used generally before the advent of the balloon and Western types, and required heavy timbers and careful workmanship. It is expensive and requires considerably more time and labor than is needed for either a balloon frame or for a Western frame. It is seldom used today in domestic work. Nevertheless, this method of framing is a good one and is used in heavy framed constructions of wood where a particularly strong structure is required.

Sill.—The sill *a*, Fig. 5, is usually 6 in.×8 in. in size, is bolted to the masonry as at *b*, halved at the corners as at *c*, and is spliced as at *d*. It is notched as at *e*, to receive the ends of the joists.

Girders.—When the building is too wide for joists to span in one length, a girder *f*, Fig. 5, is used to support the inner ends of the joists. The girder is supported at intervals by masonry piers *g*, or by posts on masonry footings, and at the ends on the foundation wall, being joined to the sill by a halved joint. The girder is shown notched for joists in the same manner as the sill.

Corner Posts and Girts.—The corner posts *h*, Fig. 5, are framed, that is, all the mortises, tenons, etc., are cut, and the posts are raised into position. The girts *i* and *j* and the angle braces *k* are framed into the corner posts, the tenons being held in place by oak pins. The corner posts are made plumb and are held in position by temporary plank braces. When 2″×4″ studs are used, these corner posts are generally 4 in.×6 in. in size, and the girts are 4 in.×6 in. in size. If the studding, however, is made of 2″×6″ material, the posts must be made 6 in.×8 in. in size, and the girts must be 6 in.×6 in., or 6 in.×8 in. in size. The angle braces *k* are made usually of 4″×4″ material, and are mortised into both the corner posts and the sill, girt, or plate.

A post is also placed in the exterior wall at the ends of the girders *f*, *p*, and *s*. The ends of these girders are framed into this post. The post would be braced by diagonal braces similar to those shown at *k*.

Studs.—In braced-frame construction, the studs are sometimes mortised into the sill, as at *l*, Fig. 5, and sometimes into the girts and plates. They usually, however, are simply butted against these members and are toe-nailed to hold them securely. Studs adjacent to openings are usually 4 in. in thickness, being formed generally with two thicknesses of the regular 2 in. studs, and are butt-jointed and toe-nailed to the plate, sill, and girt. Where 4 in. studs are used, the window

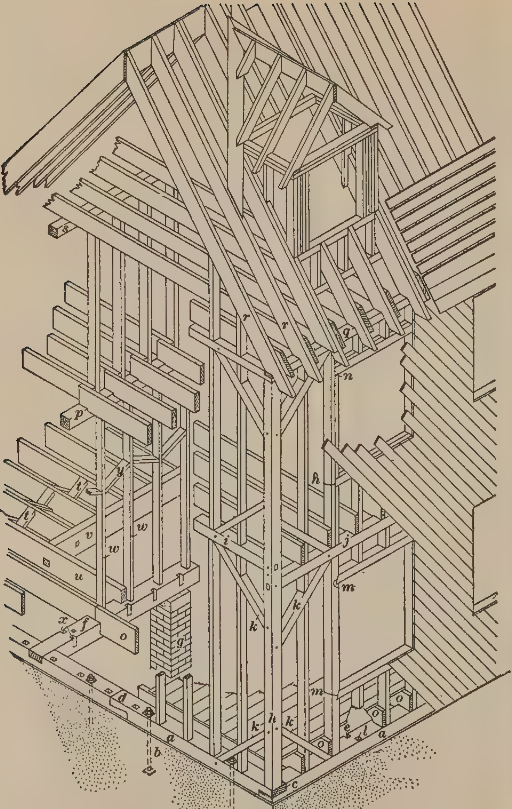


FIG. 5

sill and head are let into the studs as at *m*, but when doubled 2-in. studs are used, the sill and head are let in through one stud, as at *n*. In braced-frame construction the studs extend usually through only one story.

Joists.—The first-floor joists *o*, Fig. 5, are supported on the sill and on the girder, the ends being fitted to the notches already mentioned. For the second floor, the joists at one end rest on the girt *j* and are spiked to the adjacent studs. The other ends of the joists rest on the corresponding girt in the other end of the building, or, when the span is too great for joists in one length, on the cap *p* of a bearing partition. The joists are lapped past each other so as to secure a firm bearing on the cap and to permit of nailing the joists together.

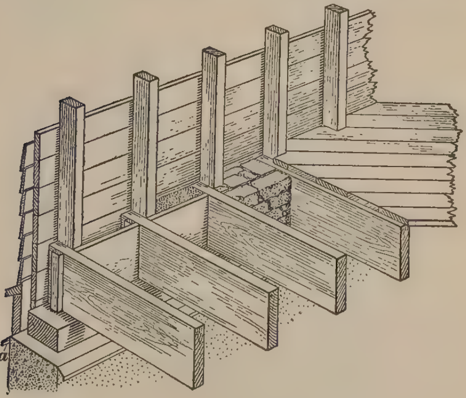


FIG. 6

Third or attic-floor joists rest on the plate *q*, which is 4 in.×4 in., or 4 in.×6 in., in size, depending on the size of the studs, and are nailed or spiked usually to the rafters *r*. They also have an intermediate bearing on a partition cap *s*. The joists in each story are braced by cross bridging, as at *t*. Openings in the floor are framed with trimmers *u*, and a header *v* is framed into the trimmers.

Termite Protection.—Destruction by termites, annually runs into millions of dollars. There are two classes of termites: ground-inhabiting termites and dry-wood termites. In the United States, the ground-inhabiting termites are found in almost every state; dry-wood termites thrive only along the southern boundary. The ground-inhabiting termites live in moist earth, shun the light, and build tunnels to reach their food.

Protective measures against termites try to eliminate moisture and food supply. In moist soil, subsurface drains should be installed to take the water away from foundations. Foundation walls of masonry should have all joints well filled with mortar, and the exterior surfaces should be parged. To avoid cracks below the wood sill, tops of concrete walls should be reinforced with steel rods.

Wood below the first floor, including the sub-floor should be given protective treatments under pressure. The common treatments are zinc salts and coal-tar creosote. The creosote treatment is the more economical. Pressure-treated wood should be cut to exact length before being treated. Nail holes and cuts at the site should receive at least two coats of preservative.

HANGERS, CAPS, AND ANCHORS

In Fig. 7 (*a*), (*b*), and (*c*) are shown the ordinary forms of wrought-iron stirrups; in (*d*), (*e*), and (*f*), are shown joist hangers; in (*g*), (*h*), (*i*), and (*j*) are hangers for use in brick walls. In (*k*) is represented a hanger for heavy girders or joists, adjustable to suit several sizes of timber by changing the bearing plate *a*, thus serving the same purpose as that shown in (*l*), which represents a hanger made in right and left parts, and fastened together by a bolt.

In Fig. 8 (*a*), (*b*), and (*c*) are represented two-member post caps; one is steel and the others are cast iron. In (*d*) and (*e*) are shown three-member post caps; in (*f*), (*g*), and (*h*), one

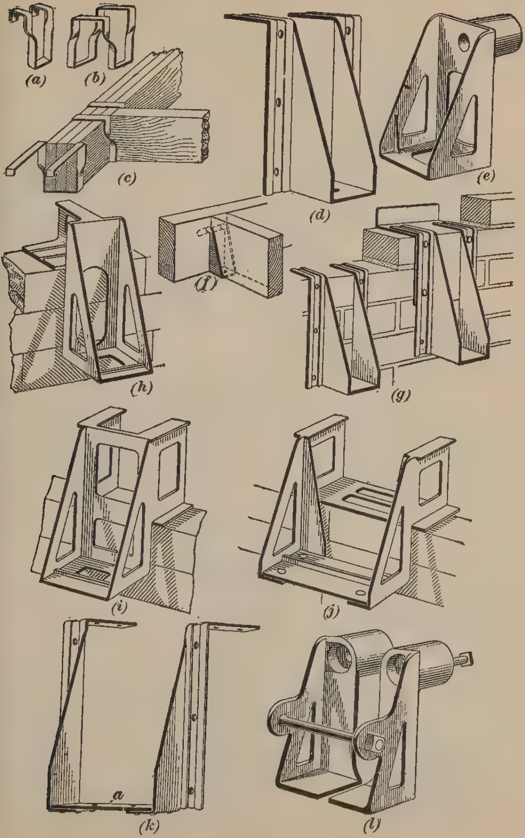


FIG. 7

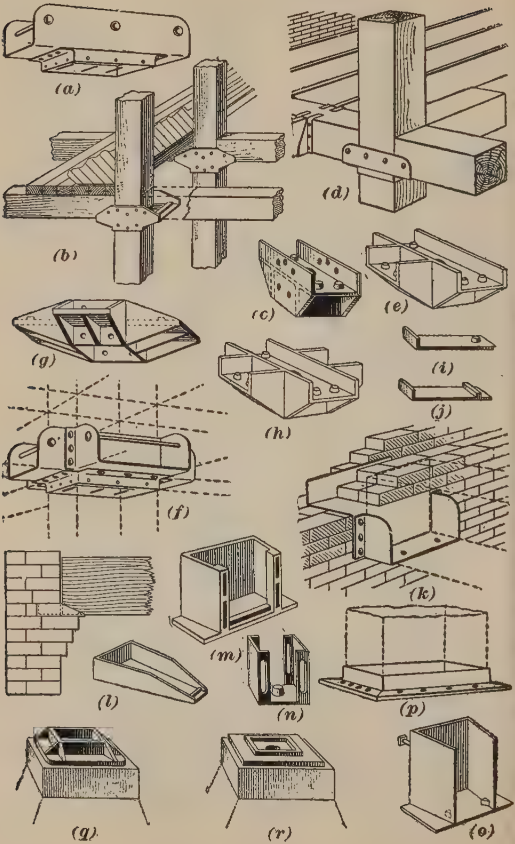


Fig. 8

steel and two cast-iron four-member post caps. In (*i*) and (*j*) are shown two cast-iron wall-bearing plates; in (*k*), a steel wall-plate hanger; in (*l*), a cast-iron box anchor for use over a edged wall; in (*m*), (*n*), and (*o*), cast-iron box anchors, the atter for I beams. In (*p*) is shown a steel base plate; and in

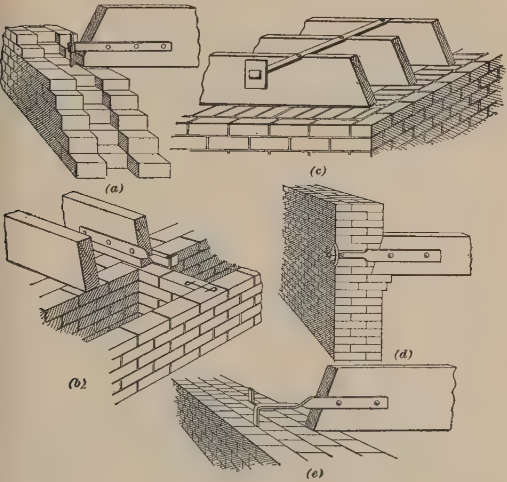


FIG. 9

q) and (*r*), two forms of cast-iron base plates. The fittings own in (*a*), (*d*), (*f*), (*k*), and (*p*) are the Van Dorn; and those (*b*), (*c*), (*e*), (*g*), (*h*), (*l*), (*m*), (*n*), and (*o*), the Goetz styles.

In Fig. 9 are shown the common forms of anchors for tying ood floor joists to masonry. They are made of wrought ar iron about $\frac{1}{4}$ in.$\times$2 in. in section and about 2 ft. long. here the anchor passes through the wall, as in (*d*), a cast-on washer, or plate, holds the anchor in place.

In Fig. 10 are shown several forms of ties for anchoring I beams, channels, etc.; (*a*), (*b*), (*c*), and (*d*) represent ordinary wall anchors; (*e*) is a tie-rod anchor running through the wall, and (*f*) shows the upper I beams connected by a fish-plate and secured to the girder by clips.

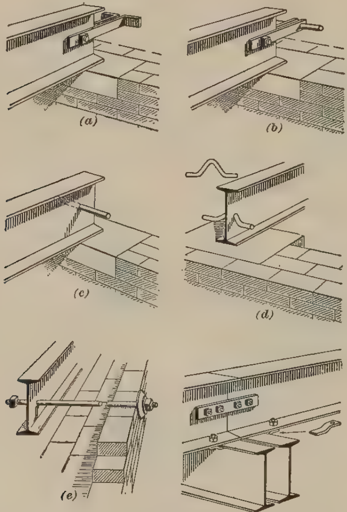


FIG. 10

When wall boxes or hangers are not used, templets, or bearing stones, should be placed under the ends of beams and girders, to distribute the weight evenly on the wall. They should be of tough stone, having a thickness of about one-third the least surface dimension, but not less than 4 in. It is well to place flat stones above the joists, etc., so that any shrinkage in the latter will not affect the wall. The building laws of some cities provide that joists shall be supported on corbels, at least 4 in. wide. This is a good construction. but a cornice is required to conceal the corbel.

PROVISION FOR SHRINKAGE

Timber, as ordinarily supplied, is seldom well-seasoned. It shrinks perceptibly across the grain, whereas the shrinkage lengthwise is negligible. All horizontal members of a frame, such as sills, girders, and joists, will shrink and partitions or stud walls resting on them will consequently settle. The framing should be designed so as to equalize this settlement between the sill and the girders, supporting the joist and partitions.

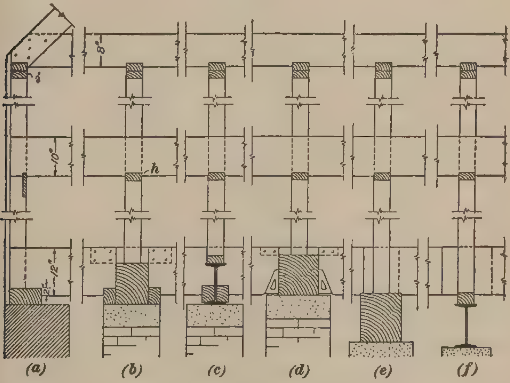


FIG. 11

In Fig. 11 the diagrams or sections show methods of framing the sill and the girders under the first tier of beams and bearing partitions. In (*a*) is a 4″×8″ sill with the ends of the joist sized or notched down on it 2 in. The shrinkage that will affect the first floor at this point will be due to that of the 4-in. material in the sill and 10-in. in the joist, or a total of 14 in. The shrinkage at the girder should be made equal to that of 14 in. of material.

In (*b*) is a wooden girder, such as is commonly used, with two 3″×4″ strips bolted to the lower edges. By sizing down the ends of the joists 2 in. on these strips the floor is subject to the shrinkage of 14 in. of material, 4 in. in the strips and 10 in. in the joist. This equalizes the shrinkage between the girder and the sill.

In (*c*), an I-beam girder is shown with 3″×4″ strips bolted to its lower part so that the shrinkable material will be 10 in. for the joists, which are sized down 2 in. on the strips, and 4 in. for the strip.

In (*d*), the joists are shown supported on hangers suspended from the girder that is 10 in. deep. The shrinkage that will affect the first floor at this point is due to the lower one-half of the girder, or 5 in. and 11½ in. to the joist, which is sized down ½ in. on the hanger. The total shrinkable material is 11½ in.+5 in. or 16½ in., or 2½ in. more than at the sill. To equalize this, the end of the joist in the hanger should be sized down 2½ in. more, which, as it has been already sized down ½ in., will amount to 3 in. To notch the joist to this extent, however, is not to be recommended.

The joists should never rest directly on top of a wooden girder, as shown in (*e*), as the settlement will be due to the shrinkage of the girder plus that of the beam, or say 10 in.+11½ in.=21½ in., or 7½ in. more material than at the sill.

A good arrangement is shown in (*f*), where an I-beam girder has a 2½″×4″ wooden strip resting on its upper flange and upon this the joists are sized down about ½ in. The shrinkable material is 11½ in. for the joist and 2½ in. for the strip, or 14 in., which is the same as at the sill. The only objection to the girder in (*f*) is that it extends below the cellar ceiling.

The girders in (*b*), (*c*), and (*d*), etc. are shown supporting bearing partitions that hold up the joists of the upper stories. These girders should also be designed so that the settlement of the upper floors shall not be more at the partition than at the outside wall. The second-floor joists at the wall above the sill rest on the ribbon, which is spiked firmly to the studs, hence there is very little chance of settlement at this point except that due to the joists themselves and the sill on the cellar wall. As the joists are 10 in. deep and are sized down on the ribbon 1 in., there is 9 in. of shrinkable material, which added to 4 in. of the sill, gives a total of 13 in.

In (*b*), the bearing partition rests on the wooden girder, which is 10 in. deep. With a partition cap *h*, 2 in. thick, the total shrinkable material at this point will be 9 in. for the joist, 2 in. for partition cap, and 10 in. for the girder, or 21 in. With 13 in. at the wall, the difference is 8 in., hence it is unwise to use a wooden girder, such as shown, to support the partition. By the use of the I-beam in (*c*), the second floor is subject to the shrinkage of 9 in. for the joist, 2 in. for the partition cap, and 2 in. for the sill laid on top of the girder, or a total of 13 in. This is the same as at the wall, thus providing an equality of settlement throughout the second floor. The use of wooden girders, as in (*d*) and (*e*), produces the same inequalities of shrinkage as in (*b*) and should be avoided.

The section (*f*) has a 2½-in. sill, a 2-in. partition cap, and, if the joists are sized down 1½ in., an 8½-in. joist, making a total of 13 in. of shrinkable material. The section in (*c*) with an I-beam girder gives the best results.

If there is no unequal settling of the second floor, there will be none in the attic joists. The 4 in. partition cap upon which the attic joists rest will shrink the same as the plate *i*. Where the outer bearings of joists are on masonry walls, the girder, holding up the inner ends and the supporting partitions, should be of steel, or else a brick wall should be used. The use of wood with the grain horizontal should be confined to the sills and caps of partitions only.

ROOF FRAMING

SLOPE OF ROOF

The slop of a roof, or its inclination to the horizontal, is usually expressed by the ratio of the total rise of the roof to its total span. Thus, ⅓ pitch means that the height of the roof equals one-third of its span. The slope may also be expressed by the vertical rise in each foot of horizontal run, as 1 in. to the foot or 6 in. to the foot; or by the angle in degrees and minutes, as 45° 0′ or 18° 26′. Fig. 1 shows several slopes expressed in all three ways.

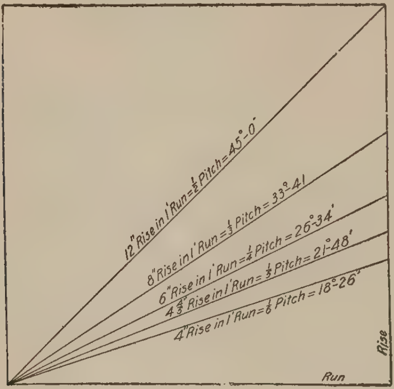

12" Rise in 1' Run = ½ Pitch = 45°-0'
8" Rise in 1' Run = ⅓ Pitch = 33°-41'
6" Rise in 1' Run = ¼ Pitch = 26°-34'
4⅘" Rise in 1' Run = ⅕ Pitch = 21°-48'
4" Rise in 1' Run = ⅙ Pitch = 18°-26'
Rise
Run

FIG. 1

The best slope for a roof is determined by considerations of appearance, cost, climate, and materials. Where the appearance of the roof is an important feature, as in churches and in buildings designed in certain architectural styles, the roof is made steep and covered with slate, tiles, or shingles; when it is necessary to be economical, the roof is kept flat and covered with cheaper materials. In climates where there is a great deal of rain and snow, steep roofs are more satisfactory, while in hot and dry climates flat roofs are better. Slate, tiles, and shingles are serviceable only on roofs with a decided slope. Metal and composition roofs, being watertight, are used for flat roofs.

The accompanying table shows the maximum and minimum slopes allowable for roofs of different materials.

TABLE OF ROOFINGS WITH MAXIMUM AND MINIMUM SLOPES

Kind of Roof	Rise per Foot	
	Maximum	Minimum
Coal-tar pitch, felt, and slag	3	$\frac{3}{8}$
Coal-tar pitch, felt, and gravel	3	$\frac{3}{8}$
Coal-tar pitch, felt, and tile or brick	3	$\frac{3}{8}$
Coal-tar pitch, felt, and cement	3	$\frac{3}{8}$
Asphalt with any of above	3	$\frac{3}{8}$
Sheet asbestos		$\frac{3}{8}$
Ready roofings		3
Tin, flat seam		2
Tin, standing seam		2
Copper, flat seam		2
Sheet iron, plain		2
Sheet iron, corrugated		3
Canvas		$\frac{1}{4}$
Shingles, wood		6
Shingles, asbestos		4
Shingles, metal		4
Slate, large size		4
Slate, small size		4
Tile, cement, flat		4
Tile, clay		4
Tile, copper or metal		4

TYPES OF ROOFS

A roof with a slope of but a few degrees is called a flat roof. In Fig. 2 are shown several types of roofs that are in common use. In (*a*) is a roof with a single slope, which, when the pitch is 30° or more, is called a single-pitch roof, a shed roof or a lean-to. In (*b*) is shown a double pitch, or gable, roof. A hip roof is shown in (*c*), where *bo*, *ao*, and *do* are the hips. In (*d*) is a roof with a gable at each of the four sides; the lines where the slopes intersect are called the valleys. The valleys are *co* in the perspective view and *o′e′*, *o′c′*, *o′a′*, and *o′g′* on the plan. A gambrel roof is shown in (*e*), the end *abd* is called a gable. A mansard roof is shown in (*f*) in which the

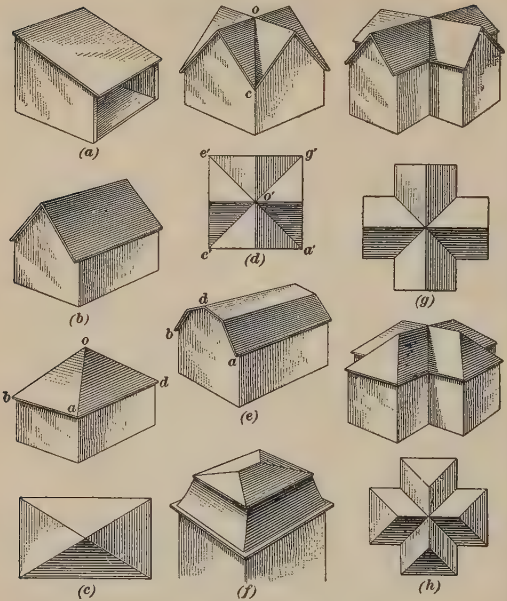


FIG. 2

lower part is almost vertical in its slope and the upper part is similar to a hipped roof; if very flat it is called a deck roof. In (*g*) are shown a perspective view and plan of a gable and valley roof and in (*h*) a hip and valley roof.

RAFTERS

Types of Rafters.—A common rafter is one that extends from the plate to the ridge as *ac′*, Fig. 3. Hip-and-valley rafters are placed at the hips and valleys as at *fe′* and *ge′* and at ki' and hi'. The rafters cut against them are called jack-rafters shown at op. The ridge rafter is placed along the ridge at $c'e'$.

Roof Plan.—In roof framing the first step is to lay out a roof plan, as shown in Fig. 3 (a), on a board or sheet of drawing paper, to a scale of, say, 1½ in. to 1 ft. This figure shows a plan of a roof of uniform pitch, the wing being the same width as the main building. One end of the roof shown is hipped, while the other ends are finished with gables, as may be readily understood by reference to the perspective view (b). In both views, the same letters refer to the same parts.

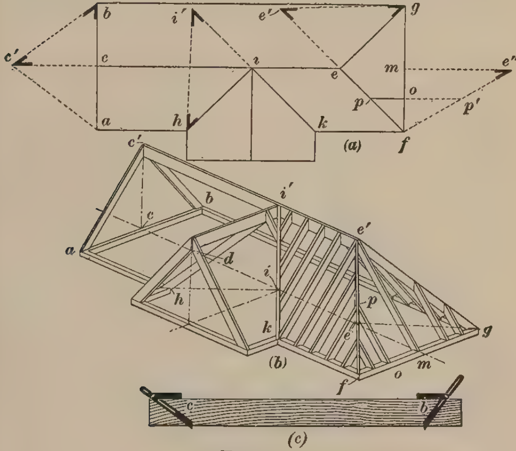


FIG. 3

Length and Cuts of Common Rafters.—At the center of ab in Fig. 3 (a), erect a perpendicular cc' equal to the height of the ridge above the wall plates; join c' and b; then, the angle at b is the foot-cut, and that at c', the plumb-cut of the common rafters. The length may be found by scaling. The angles are transferred to the rafter by means of a bevel as shown in (*c*), in which *b* is the foot-cut, and *c* the plumb-cut.

Length and Cuts of Hip-and-Valley Rafters.—On the line that represents the hip on plan, as *eg* in Fig. 3 (*a*), erect a perpendicular *ee′* equal to the height *cc′* of the ridge; join *e′* and *g*; the angles at *e′* and *g* are the plumb- and foot-cuts, respectively, and the length may be found by scaling. The lengths and cuts for the valley rafter *ih* are in this case the same as for the hip rafter, and are found in the same way, as shown at *h* and *i′* in (*a*) when revolved.

Length and Cuts of Jack-Rafters.—Erect a perpendicular *me″* at the center of the span *fg*; with *f* as a center, and *e′g*, the true length of the hip rafter, as a radius, strike an arc cutting *me″* at *e″*; join *f* and *e″*; then the angle at *e″* is the cheek-cut. The foot- and plumb-cuts will be the same as for the common rafters. The length of any jack-rafter as *op*, is found by prolonging it to cut *fe″*, as at *p′*; then *op′*, measured by scale, is the length of *op*.

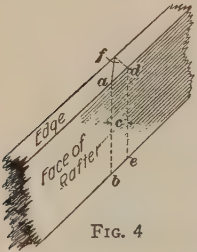


Fig. 4

Cheek-Cut for Rafters of Any Pitch.—On the face of the rafter draw the plumb-cut, as at *ab*, Fig. 4; parallel to *ab* draw *de* at a distance *c* equal to the thickness of the rafter; square over from *d* to *f*, and join *f* and *a*, thus obtaining the cheek-cut.

Lengths of Hip or Valley Rafters; Wall Plates at Right Angles.—Having fixed the rise and run by the square for the common rafter, take 17 in. for the run of the hip or valley rafter. Thus, if the roof is one-third pitch, *i.e.*, 8 in. rise and 12 in. run, the hip or valley rafters will have the same rise, 8 in., and 17 in. run. These results are a trifle large.

Lengths of Jack-Rafters.—Having obtained the lengths of the first two adjacent jack-rafters at the toe of the hip rafter, by the graphic or other method, measure the difference between their lengths, and keep adding this difference for the subsequent ones.

Profiling Hip and Jack-Rafters for a Curvilinear Roof.—In Fig. 5 the arrangement of the rafters is shown in plan, *eg* being a hip rafter, and *hl* a jack-rafter. In the elevation, $b'c'$ is the span and oe' is the rise. To find the shape of the hip rafter *eg*, make $e''g''$ equal in length to *eg*, and lay off $e''k''$, $k''h''$, etc., equal to *ek*, *kh*, etc. Erect perpendiculars at e'', k'', h'', etc. At *e*, *k*, *h*, *c*, etc., drop, perpendiculars cutting the curve $e'g'$ at k', h', etc. From e', k', h', etc. draw horizontals cutting perpendiculars from e'', k'', h'', etc., at the points e''', k''', h''', etc. A curve drawn through these points gives the required outline of the hip rafter. The shape of the jack-rafter *hl* is the same as the curve $h'g'$.

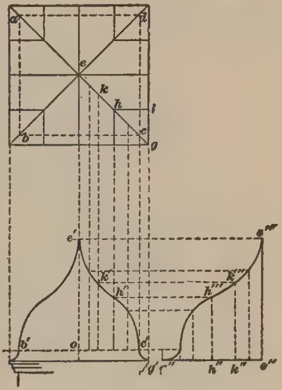


FIG. 5

WINDOWS

AREA

The following proportions are given by different authorities for fixing the amount of window surface: (1) One-eighth of the wall surface should be windows. (2) The area of glass should equal at least one-tenth of floor area. (3) One square foot of glass should be allowed to 100 cu. ft. of interior space to be lighted. Class rooms in schools should be provided with a glass area, preferably on the long side of the room, equal to one-fifth or one-fourth of the floor area of the room. It is better to have a surplus than a deficiency of light, for if too bright, it can be regulated by blinds or shades.

DESIGNS

The height of the window should be twice its width. The glass line of windows in dwellings should be about 30 in. from the floor for principal rooms, and about 36 in. for bedrooms. In all cases, the heads of windows should be as near the ceiling as the construction and interior scheme of treatment will permit, to obtain better light and ventilation. The meeting rails of window sash should be placed not less than 5 ft. 9 in. above the floor; otherwise, the rail will be on a level with the eyes, obstructing the view.

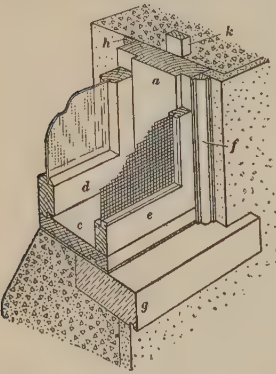


Fig. 1

It is difficult to make sash that are hinged and open inward water-tight, and those opening outward are likely to be injured by the action of wind, so that for general service the best results are obtained by use of sliding sash, counterbalanced by means of chords or chains and weights.

Sash stops should be fastened with screws passing through slotted sockets so that they can be adjusted, thus preventing the sashes from rattling.

CONSTRUCTION

Cellar Windows.—For cellar windows, which are often not high enough to permit the use of sliding sash, a single sash hung in a rabbetted frame is used. In Fig. 1 is shown a view and in Fig. 2 a working detail of such a frame in which *a* is the jamb, or side; *b* is the head, or top; and *c* the sill. The head and jambs are rabbetted to take the sash *d* and a mosquito guard *e*. The staff bead *f* is nailed tightly into the corner formed by the outside of the frame and the masonry jambs, to prevent the entrance of wind and rain. A groove in the

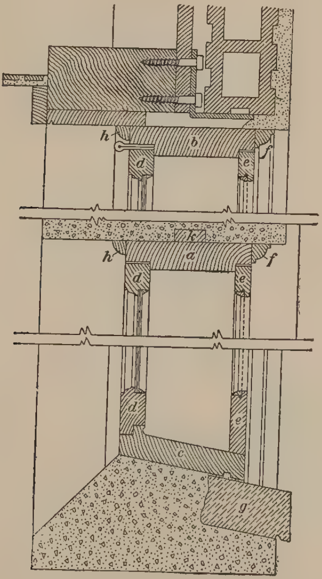


FIG. 2

nderside of the sill, where it rests on the stone sill *g*, is filled ith mortar when the window frame is set, thus preventing he passage of air and water. The interior finish is generally mitted in cellar windows, but a simple molding *h* is sometimes nailed in the corner. The frame is shown in a concrete wall and the strips *k* are nailed to the jambs to prevent the frame from slipping out.

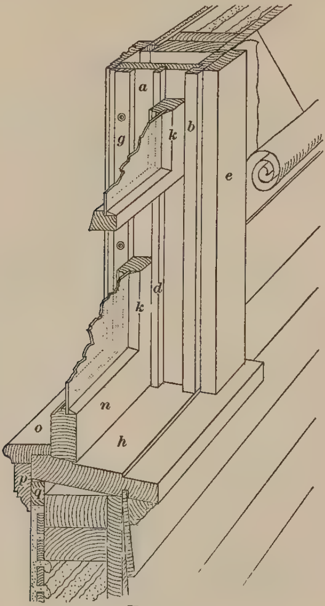
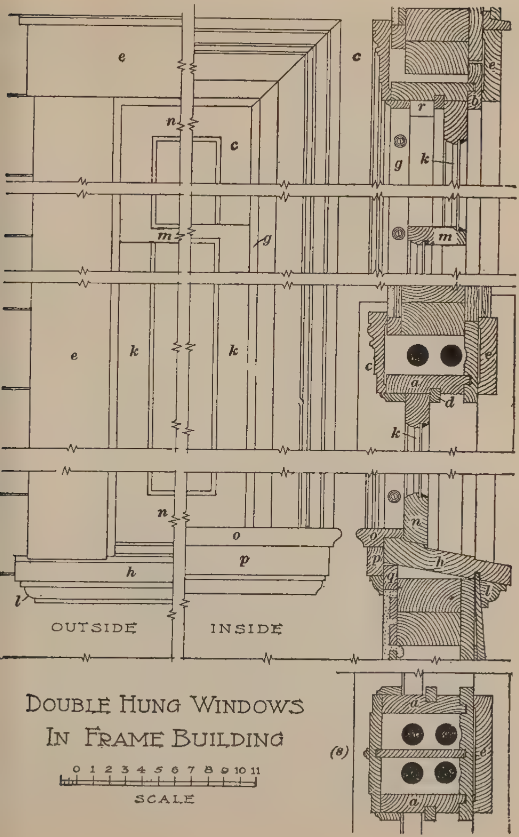


Fig. 3

Double-Hung Windows.—In Fig. 3 is shown a view of a window frame with sliding sash, for a frame building. In Fig. 4 is shown a working detail of the same. Windows of this type are known as double-hung windows. The pulley stile *a* may be from 1⅛ to 1⅜ in. thick, and should be tongued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(8)
e
a
DOUBLE HUNG WINDOWS
IN FRAME BUILDING
0 1 2 3 4 5 6 7 8 9 10 11
SCALE

FIG. 4

into the blind stop *b*, which is ⅞ in. thick. These tongues make the stiles rigid, preventing them from deflecting sidewise when the sashes are being operated, and form an excellent stop for wind and rain. An open space of from 2 in. to 2½ in. is left between the back of the pulley stile and the rough stud, thus forming a box for the weights.

A movable pocket for the insertion of the weights is cut out of the lower portion of each pulley stile on the inside so that it may be covered by the lower sash. The parting strip *d* is ½ in. or ⅝ in. thick, and passes into a groove ⅜ in. deep in the pulley stile. The outside casing, or architrave, *e*, 1⅛ in. thick × 5 in. wide, is firmly nailed through the blind stop into the pulley stile and to the wall sheathing. The inner face of the window frame is finished with a casing, or architrave *c*, the width being sufficient to cover the plaster joint. The sash stop *g*, from ½ in. to ⅝ in. thick, is secured with round-headed screws passing through slotted sockets for adjustment. This member should not be less than 1½ in. in width to take the window shade properly. The members *g*, *d*, and *b* should be kept in line, their projection beyond the face of the pulley stile being regulated by the thickness of the sash stop.

The sill *h* is made of 2-in. stock. The bevel formed on the inside of the lower sash and on the corresponding part of the sill, tends to force the sash, when closed, against the parting strip *d*. The rabbet in the sill just back of the outer face of the lower sash permits the water to drip from the face of the sash. The rabbet at the outside of the blind stop is to take the bottom of the blind or shutter. The sill is plowed on the under side to receive the clapboards or siding and a bed molding is fitted underneath the sill and returned against the siding at either end as shown at *l*. At *r*, is a block placed on the pulley stile between the parting strips and the stop-bead, which is of the same thickness as the stop-bead; this prevents the lower sash from being raised so high that the sash fastener can strike the head of the frame. A mullion is shown in Fig. 4 (*s*), with a partition between the weights of the different windows.

For durable work, the window frames should be put together with stiff white-lead paint, particularly adjacent to the sill. The sashes *k* are made from $1\frac{1}{8}$ in. to $1\frac{3}{4}$ in. thick. The sash should not be made more than $1\frac{3}{8}$ in. thick where 4-in. wall studs are used. If thicker sash is required, the studs should be made 5 in. or 6 in. wide. The meeting rails *m*, $1\frac{1}{8}$ in. to $1\frac{3}{8}$ in. thick, according to width of opening, may be double- or single-beveled, as shown, so that they will come tightly together when closed. The lower rail *n* may be from 3 in. to

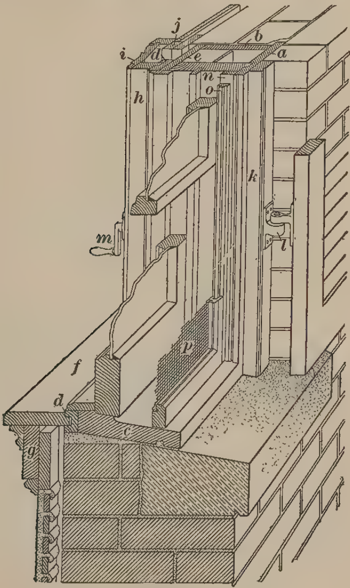


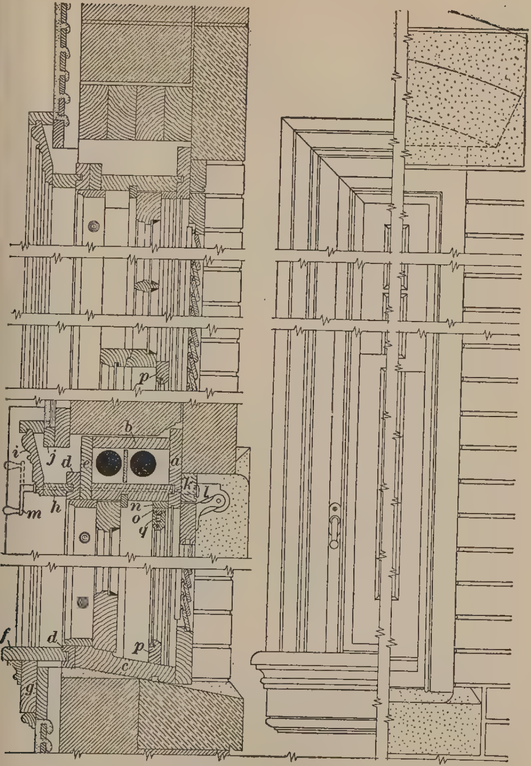
FIG. 5

$4\frac{1}{2}$ in. wide, and should be accurately fitted to the sill. A stool *o* and an apron *p* are fixed to the edge of the sill and to a plaster ground *q*, and finished with a bed mold as shown. The length of the apron should be equal to the width from out to out of casings, or architraves, and have the moldings returned.

In Fig. 5 is shown an isometric sketch and in Fig. 6 a working detail of a box-frame window suitable for a stone or brick wall. The general design and construction of the frame and sash are similar to that shown in Fig. 3; the only changes being in parts that require to be adapted to a new condition. In brick walls, it is usual to set the window frames during the erection of the walls, thus facilitating the plumbing of the brick jambs, particular care being taken to brace the frames, in order to keep them plumb and level. By extending the outside casing *a* 1 in. beyond the back lining *b*, the frame can be firmly held in place in the wall. The sill *c*, made of 2-in. plank should be bedded in haired lime mortar, or, for first-class work, stiff white-lead paint and white sand. The groove on the bed permits the formation of a mortar tongue, making it practically air-tight; the slightest shrinking and warping of the sill allows the passage of air and water, unless this device is adopted. A $\frac{7}{8}$-in. finished casing *d* may be attached to the box casing *e*, after the building is ready for trimming, thus covering its marred condition. The window stool or seat *f* is tongued into the casing *d*, providing for its expansion and contraction; it is generally finished with a molded apron *g*. The jamb casing *h* is tongued into the finished casing *d*, and the opening trimmed with a casing, or architrave, such as *i*, nailed to the jamb casing *h* and the plaster ground *j*.

The hanging stile *k* in brick-set frames is attached thereto before setting, but where outside blinds are not used, an angle mold may be substituted. Before the window frames are given the final coats of paint, the hanging stiles may be removed and the joint between the frame and the brickwork calked with oakum to make a weather-proof joint, after which the hanging stiles are replaced.

In stone walls, window frames are not usually set until the building is roofed and is prepared for the plastering, or has



DOUBLE HUNG WINDOWS IN BRICK BUILDING

0 1 2 3 4 5 6 7 8 9 10 11

SCALE

FIG. 6

the plastering completed. There are two reasons for this, the principal one being the difficulty experienced in setting jamb stones and lintels while the frame is in position, and the second that, with all due care, the frames are more or less damaged during building operations and are never so true to line, level, and plumb as those set in place after the walls are completed. When set in this latter order, it is necessary to encase the masonry openings with screeds or wooden strips, carefully alined and plumbed. The frames are secured in place by means of hold-fasts or wall plugs.

Screens.—Figs. 5 and 6 also show screens and blinds fitted to the frame. Where both blinds and outside screens are used, a special piece *n* is nailed to the pulley stiles and upon this a strip, or track, *o* is fastened, which receives the screen *p*. Space must be left between the face of the screen and the inside face of the blind for the rod that is fastened to the slats in the blind, and for the hardware where the ordinary blind fasteners or adjusters are used.

The screens *p* are made with hardwood or metal frames, with a wire mesh stretched tightly over them. The cheapest screens have steel-wire mesh and consequently need frequent painting to preserve them from rust. The best screens are covered with a mesh made of copper bronze, which is not subject to rust. The mesh is made with 14 to 16 wires to the inch. The screens are provided with springs *q*, which are concealed in the grooves at the sides, and will remain stationary in any position.

Blinds and Shutters.—Blinds are made with slats, either fixed or movable; shutters are solid and generally paneled. Both blinds and shutters are generally made $1\frac{1}{8}$ in. in thickness and are hung on L-shaped hinges, which allow of their clearing a reveal, or an outside architrave, and lying flat against the wall of the house. They are secured by blind fasteners or by blind adjusters. Devices are made that enable a person to open or close the blinds or shutters from within the house, without the necessity of opening the window, and which hold the blind firmly in any desired position. A device of this kind is shown at *l* and *m*. The box *l* contains a worm-gear that is operated by turning the crank *m*, thus opening or closing the blind.

Storm Sash.—Storm sash are sometimes provided for windows and are made generally of $1\frac{1}{8}$ in. thick material and are hung in the rabbet that is occupied by the blinds when closed. The blinds are either removed or left open while the storm sash are in place.

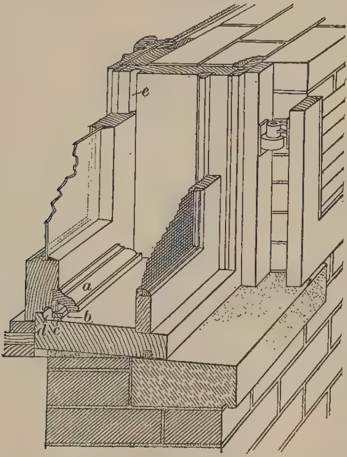
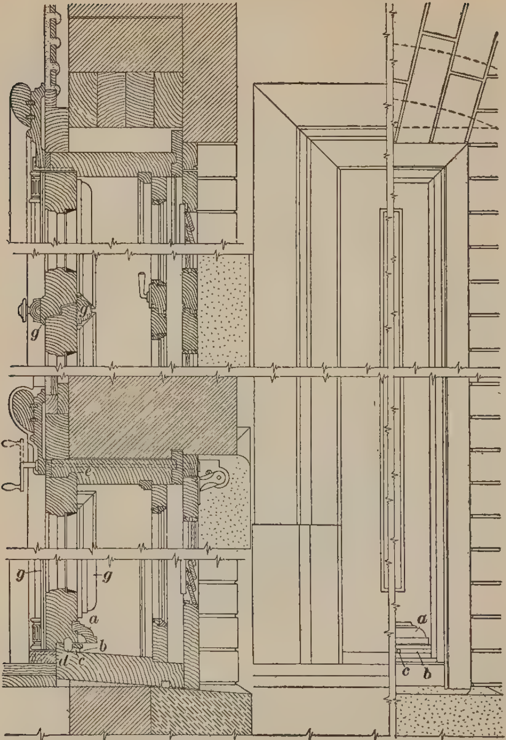


Fig. 7

Casement Windows.—Casement windows are those that have sashes hinged at the sides and swinging in or out like doors. French windows are casement windows, having two sashes with meeting stiles down the center. They are generally carried down to the floor and are high enough to be used as doors. Casement and French windows are difficult to construct so that rain will not beat in, but as they are very effective from the standpoint of design, different devices have been



FRENCH WINDOWS IN BRICK BUILDING

FIG. 8

tried to make them serviceable. A fairly satisfactory detail of a French window is shown in Figs. 7 and 8, showing the most effective treatment of the sill and jamb, which are the weak features of these windows. The sill should be made of 2½-in. material and rabbeted and the surface curved as shown at *b*.

This feature intercepts rain that is blown against the joint of the sash and the sill. If, however, water should be forced into the joint it would fall into a gutter, *d*, which is plowed in the sill and which is drained, in turn, through the holes *c*, which are about ⅜ in. in diameter and about 2 ft. apart. The drip mold *a* on the bottom rail of the sash also aids in stopping rain that may be blown against the bottom joint and forms a drip for water that washes down the face of the sash. The jambs instead of having straight rabbets, like those of a door, have semi-circular channels worked into them, as shown at *e*, into which a half-round projection on the stile of the sash works. The meeting stiles are designed with beveled rabbets, so that one sash can be opened at a time. Astragals *g*, are placed on the outside and the inside so that both shall be on the center. The inside astragal, if the window is to be fitted with Cremorne or Espagnolette bolts should have a flat surface, 1¾ in. in width, to receive them.

The sash in casement windows should be made thicker than are used for double-hung sash, as there is more strain upon them due to their being hung on one side. For small casements, 1¾ in. is a sufficient thickness and 2½ in. or more for large sash.

In Fig. 7, outside mosquito screens are shown. They are made in two parts, like the sash, with vertical meeting stiles and cover the entire opening. Blinds can be used on these windows if shutter workers are provided as shown.

Weather Strips.—Weather strips are made of rubber strips mounted on wooden moldings, but as the rubber soon becomes hard and brittle these are not to be recommended. The best kinds of weather strips are made of strips of a non-corrosive metal and fitted to the sash so as to keep out wind and rain. There are several makes of these strips all of which have merit

GLASS

Common Window Glass.—Common window glass is made in flat drawn sheets and has a more or less wavy appearance. It also has some defects, such as beads, scratches, and strings, which are present to some extent in all common glass. Grade A or quality A may have several of these defects, while grade *B* should contain fewer defects. These grades of glass are widely used in private dwellings, apartment houses, hotels, schools, hospitals, and public buildings. The defects should not appear in the central area of the glass, but should be confined to the outer edges of the panes or lights. Window glass is made in two thicknesses, single-strength and double-strength. The weights and thicknesses of these two kinds are shown in the accompanying table.

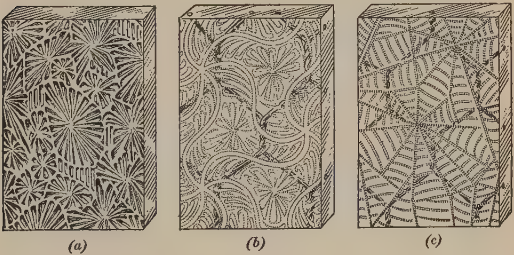
APPROXIMATE WEIGHT AND THICKNESS OF GLASS

Variety	Weight per Sq. Ft. Ounces	Thickness Inches
Window glass, single-thickness	18.9	$\frac{3}{32}$
Window glass, double-thickness	26.0	$\frac{1}{8}$
Crystal glass	39.0	$\frac{3}{16}$
	45.0	$\frac{7}{32}$
	51.0	$\frac{1}{4}$
Plate glass, polished	39.0 to 65.0	$\frac{3}{16}$ to $\frac{5}{16}$

Crystal Glass.—Crystal glass is a heavier sheet glass with a uniform, brilliant surface and uniform thickness. It is lower in price than polished plate glass and is used instead of plate glass at a considerable saving. It is used in the better grades of buildings and in the lower sashes of windows of dwellings where a better grade of glass is required.

Plate Glass.—Plate glass is made by rolling the melted glass on a table to an approximately even thickness and then giving the surfaces a high polish. The greatest width that can be rolled is 164 in. and the greatest length 260 in. A plate with an area of about 240 sq. ft. is about as large as can be made economically. The thickness varies from $\frac{3}{16}$ to $\frac{5}{16}$ in. Plates more than 75 sq. ft. in area should be at least $\frac{1}{4}$ in. thick. Plates over 100 sq. ft. in area should be $\frac{1}{4}$ in. full. Plate glass is also made of greater thickness for special purposes.

Polished plate is graded as glazing quality, which may contain small bubbles, fine scratchings, etc.; selected glazing, which is almost free from defects and is used in high-class residences, show-cases, etc.; and silvering quality, which is as near perfect as possible and is used for making mirrors.



(a) (b) (c)

FIG. 1

Mirrors.—Mirrors are made by two processes. The patent back is formed by treating the glass with two coats of nitrate of silver, then varnishing and painting. This kind of mirror will last about 10 or 12 yr. The old process consists of placing a layer of tin-foil on a table, and on this a thin film of mercury upon which the plate of glass is floated, and then pressed down by weights. The result is a permanent back.

This method is not used much at the present time, as it is more expensive and the process of manufacture is deleterious to the health of the workmen.

Figured Rolled Glass.—Rolled glass is made with figured or patterned surfaces that make it translucent, but in many cases causes a better transmission of light than plain glass. This glass is made in various patterns, such as Florentine, maze, and cobweb, which are shown in Fig. 1.

Wire Glass.—Wire glass has a wire mesh embedded in the body of the glass, as illustrated in Fig. 1 (*b*) and (*c*). This product has a great value as a fire-retarding material. Even when the glass is cracked by intense heat, the fragments are held in place by the wire that it protects. It is furnished either clear or with a figured surface as shown.

Prism Glass.—Prism glass is designed to deflect rays of light and direct them into rooms and buildings that do not obtain sufficient light through plain glass. It is generally made so that the prisms project from the inside or under side of the sheet while the other side has a plain surface.

OUTSIDE FINISH

Water-Table.—Before the siding is put on the sheathed frame of a wooden building, a water-table *de*, Fig. 1, is placed all around the structure, with its lower edge extending about 1 in. below the sill. The water-table has the drip mold *d* as its top member, and this has a tongue *f* extending up behind the siding. The water-table serves the purpose of shedding the water that runs down the side of the house, away from the foundation walls.

Sheathing Paper.—One or more thicknesses of heavy felt or resinous building paper are laid over the sheathing, and serve to prevent drafts from penetrating the walls, also to prevent the transmission of heat. Strips of this paper or felt are tacked to the backs of corner boards, window and door frames, pilasters, etc., before fastening them in place.

Corner Boards.—Corner boards are used where a building is covered with siding. Where shingles are used in place of siding corner boards are frequently omitted. Corner boards consist of two strips of board put together so as to form an angle and are nailed to all the corners of the building and the siding is cut to fit in tightly between them. Pilasters are sometimes used in place of corner boards.

Siding.—When the water-table and corner boards are in place and the window and door frames are set, the siding is put on in horizontal courses over the paper. It is nailed through its lower edge into the sheathing and the nails are set, or driven so that the heads are slightly below the surface of the boards. After the boarding receives its first coat of paint these holes are filled with putty and the nails concealed and protected. The best woods to use for siding are white pine, cypress, and redwood. Yellow pine is also used but requires special care in painting.

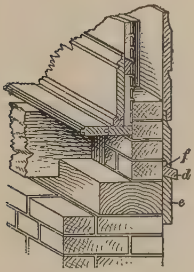


FIG. 1

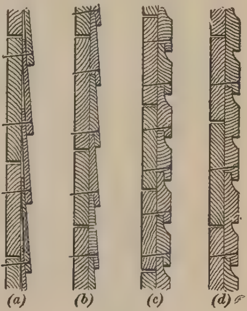


FIG. 2

Beveled siding, shown in Fig. 2 (*a*), consists of sawed and planed boards about 16 ft. long. It is manufactured in 4 in., 5 in. and 6 in. widths, is $\frac{5}{8}$ in. thick at the bottom edge and about $\frac{1}{4}$ in. thick at the upper edge. This siding is put on with a lap, as shown, the upper board covering the lower one about $1\frac{1}{2}$ in.

Rabbetted, or, shiplap, beveled siding is shown in (*b*). This siding has the advantage that the nails go through one edge only, thus leaving the board free to expand and contract.

Drop, or Novelty, siding, shown in (*c*) and (*d*), has a uniform thickness of $\frac{3}{4}$ in. to $\frac{7}{8}$ in. and a width of $5\frac{1}{2}$ in. In very cheap work the siding shown in (*d*) is used, which has a groove worked in the middle of the face in imitation of a joint.

Shingling.—Shingles are used to cover the outside walls of wooden houses. They give a less formal effect than siding and are capable of various effects, which are produced by the use of fancy butts and by staining the shingles. A shingled wall is slightly more expensive than one covered with siding, but it generally forms a more weather-proof covering.

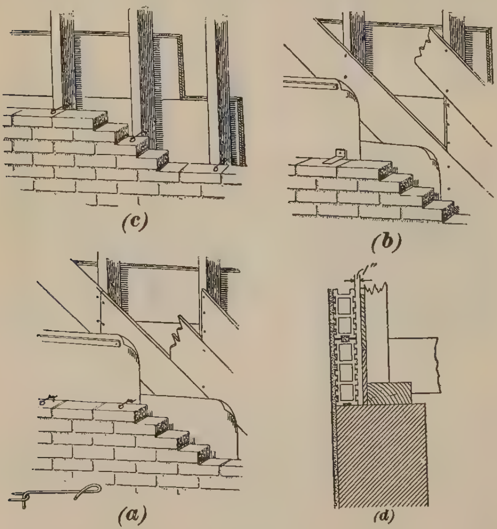


FIG. 3

Veneered Buildings.—Frame buildings are often veneered with a 4-in. wall of brickwork as shown in Fig. 3 (*a*), (*b*), and (*c*), or with a 3-in. or 4-in. wall of terra-cotta blocks which may be stuccoed, as shown in (*d*). In such cases, the frame of the building should be set back from the face of the foundation wall as shown in (*d*). An air space of 1 in. should be left between the masonry veneering and the sheathing boards. Anchors are used as shown to tie these veneering walls to the studs or sheathing boards. Sheathing paper applied to the boarding, as shown in (*a*) and (*b*), adds greatly to the comfort of the house.

Eaves and Gutters.—Metal gutters, or eaves troughs, are generally made of galvanized iron and have a semi-circular section with rolled edges as shown in Fig. 4. They are hung from the eaves by means of adjustable hangers, which can be regulated to form a pitch. From the fact that they cannot be hung level, they detract from the appearance of the eaves. When made with a molded front and with a false bottom by which the pitch is formed, they can be used so as to give a satisfactory effect.

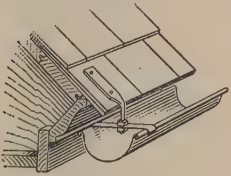


FIG. 4

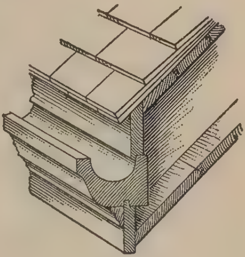


FIG. 5

Cypress gutters are made of logs of cypress in which a channel is formed having a suitable pitch. They are spiked to the ends of the rafters and are very durable. The front edge is molded so as to form the upper member of a cornice so that other features of a cornice can be added below, as shown in Fig. 5. Where the length of gutter required exceeds 16 ft. two or more lengths are butted together and the joints covered with sheet metal.

In Fig. 6 is shown a strong and durable box gutter suitable for either a frame building or for a brick or stone structure, having a wooden cornice. A series of lookouts are nailed to the wall studs (or built into the brickwork or stonework), forming a solid base for the cornice and gutter. The width of the lookouts may be varied, to obtain the grade for the gutter bed, or it may be uniform, strips being nailed to the upper edges of the pieces. On a gable roof, the cover-plate over the crown mold should be kept in line with the sheathing on the roof slope. In lining this gutter, if a strip of hoop iron is tacked to the fillet of the crown mold, with its lower edge kept ¼ in. below the mold, the lining may be tightly clasped over the strip, and face-nailing dispensed with, thus making a neat and durable job. The lining should pass behind the eave mold, but need not be carried up the slope. The end of the gutter is closed at the gable, so that the crown mold can run up the fascia and be continuous. The usual practice is to leave a space of from 4 in. to 6 in. between the closed end and the fascia of the gable.

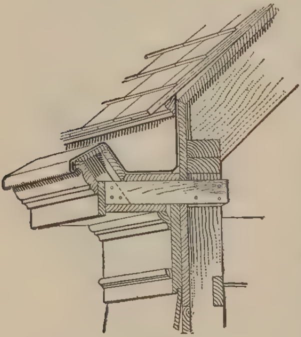


FIG. 6

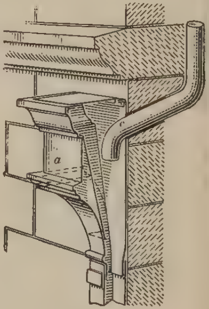


FIG. 7

Leaders.—Leaders or conductors, carry the water away from the gutters. They are hung against the walls of the building and are generally made of galvanized iron or copper.

A leader with a circular section is a poor one to use in a climate where severe freezing occurs. It is apt to be filled with ice and burst as its circular section does not permit of its yielding. A leader with a corrugated or rectangular section yields to pressure by changing its shape, thus avoiding rupture.

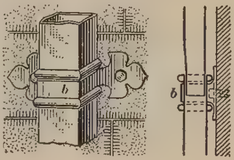


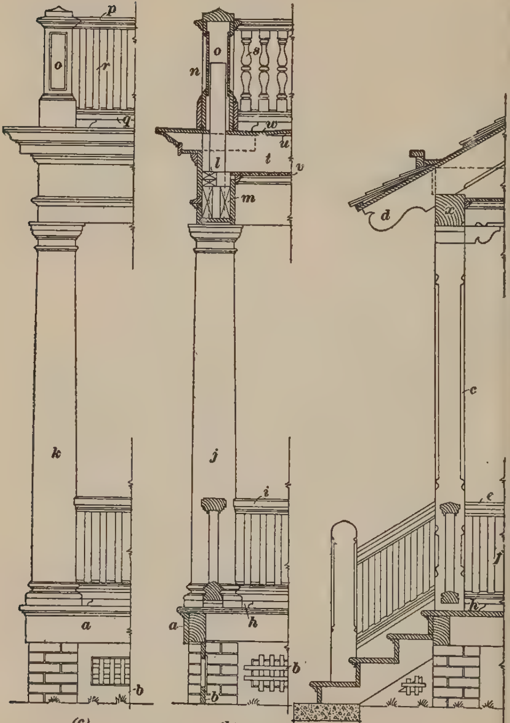
FIG. 8

Leaders are often provided with ornamental heads, as *a* in Fig. 7, and bands, as *b* in Fig. 8, which are formed of sheet metal. The water is conveyed into the leader through a goose-neck *c*, Fig. 7.

The proper sizes of leaders will vary with the climate and the rain fall. A safe rule is to allow 1 sq. in. of sectional area of leader pipe for every 75 sq. ft. of flat roof area. No leaders should be less than 2 in. in diameter.

Porches and Piazzas.—Where the floor of the piazza is of wood, the joists supporting it should be framed parallel to the house so that the floor boards may be laid at right angles to the house and have a pitch of at least $\frac{1}{8}$ in. to the foot. The joists are supported on girders that rest on the foundations of the house and upon piers of brickwork or stonework under the front of the piazza. A fascia *a*, Fig. 9, is carried around the front of the piazza covering the floor framing. The edge of the floor extends over this fascia and is finished with a semicircular profile, called a nosing, under which a cove or other molding is placed. The spaces between the piers from the under side of the fascia to the ground are usually filled in with a screen, or lattice, generally formed of wooden strips enclosed in frames as at *b*.

The posts, columns, cornices, balustrades, and other features of the piazza depend for their form on the style of design of the building. When a Gothic effect is desired details like those shown in (*a*) may be used. The posts may be square and the sharp corners beveled off forming chamfers, as at *c*. This chamfer, which does not extend the full length of the post

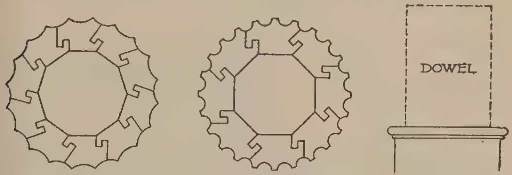


(c) (b) (a)

FIG. 9

but is stopped at given points, is called a stop-chamfer. The rafters and plate may be decorated with stop-chamfers and the ends of the rafters may have scroll-sawed ends, as at *d*. The roof boards are shown nailed to the tops of the rafters with the face side down. They should be thick enough to take the nails that hold the roofing material, which is nailed directly to the roofing boards, and not have the points of the nails come through the exposed face.

The railing consists of the top rail *e*, the bottom rail *g*, and the balusters *f*. The rails are designed with a slight wash or slope on the upper surfaces. Top rails are sometimes made wide enough to form a shelf or seat 6 in. or 8 in. in width. The bottom rail where the posts or columns of the piazza are far apart should be supported on blocks *h* resting on the floor. For ordinary buildings, stick balusters made of $\frac{7}{8}$ in. stuff $1\frac{1}{4}$ in. or $1\frac{3}{8}$ in. wide, are frequently used.



DORIC FLUTING IONIC FLUTING

FIG. 10

In buildings designed in the Renaissance or Colonial styles, columns and entablatures are used, as shown in (*b*) and (*c*). The flat roof shown is formed by the roof beams or rafters *t*, which extend from the house to the plate *l* which rests on the girders *m*. The girders are supported on dowels on the columns as shown in Fig. 10. The boarding *w*, Fig. 9, is nailed on top of the rafters, upon which furring *u* is first nailed to form the pitch, and ceiling boards *v*, $\frac{3}{8}$ in. thick, are nailed on the under side to form a finished ceiling. The entablature is formed as shown and supported by the necessary blocking or furring.

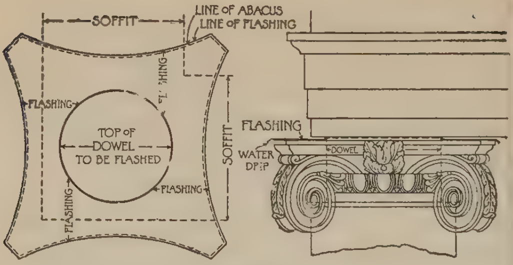


Fig. 11

A balustrade *n* is frequently built around the roof of the piazza with newels *o*, top rail *p*, bottom rail *q* and either stick balusters *r*, or turned balusters *s*. The juncture of the newels with the roof should be carefully flashed.

The columns *j* and *k*, are generally built up, when more than 6 in. in diameter, as they are liable to check or crack if made solid. There are several concerns that make a specialty of manufacturing built-up, or lock-joint columns. These columns are built up of staves or strips, as shown in Fig. 10, 2-in. stock being used for columns up to 16 in. in diameter. They are made plain or with Doric or Ionic flutings. The shafts of the columns are turned with a fillet at the top and the bottom and with an entasis, or swelling, characteristic of the order. The columns are fitted with wood or composition capitals, Fig. 11, which fit around the dowels. Upon the dowels, the roof structure of the porch is supported. Composition capitals are generally made of a fibrous composition that will stand the effects of

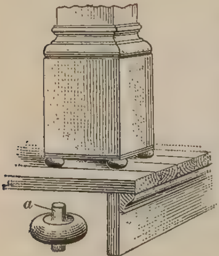


Fig. 12

weather better than wood. The tops of capitals, however, should always be well flashed.

The bases of columns and posts resting on the floor of the porch will, in time, decay on account of moisture finding its way beneath them. A device for avoiding this result is shown in Fig. 12. It consists of four metal buttons, *a*, with dowels, that are let into the under side of the base and into the floor, and keep the base free from the floor. Another method is to make the square part of the base of metal as shown in Fig. 13.

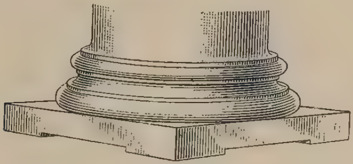


FIG. 13

Where the floor of a porch or piazza is close to the ground, it is often made of masonry and finished with cement, brick, or tiles.

Piazzas are often enclosed with sash and used as sun rooms, and are sometimes provided with fireplaces. In summer, the sash are removed and where necessary the piazzas are enclosed with mosquito screens.

Flagpoles.—For a flagpole extending from 30 to 60 ft. above the roof, the following proportions give satisfactory results: The diameter at the roof should be made $\frac{1}{50}$ the height above the roof, and the top diameter $\frac{1}{2}$ the lower. To profile the pole, divide the height into quarters; make the diameter at the first quarter $\frac{15}{16}$; at the second quarter, $\frac{7}{8}$; and at the third quarter, $\frac{3}{4}$ of the lower diameter. Thus, if a pole is 41 ft. 8 in. high above a roof, the lower diameter is $\frac{1}{50}$ of 41 ft. 8 in., or 10 in.; that of the first quarter, $9\frac{3}{8}$ in.; the second, $8\frac{3}{4}$ in.; the third, $7\frac{1}{2}$ in.; and the top, 5 in.

Flagpoles may be made of spruce or pine; Oregon pine is preferable, and where the entire sap-wood is removed by cutting the pole out of the heart of a large trunk, a durable pole is obtained. The pole should be painted with at least four coats of white lead, and should be capped by a suitable finial, terminating in a gilded ball. Halyards should be at least ½ in. in diameter, and be of waterproofed, braided cotton, or Italian hemp.

INSIDE FINISH

JOINTS IN MILLWORK

A beaded joint, shown in Fig. 1 (*a*), is one disguised by a quirked bead that is worked on one edge; this joint is used in matched lining, etc.

Butt joints, shown in (*b*), (*c*), and (*d*), are used for returns, when one piece is fitted to the edge of another, and may be rabbeted, matched, or plain-butted, as required.

The feathered or slip-tongue joint shown in (*e*), formed by plowing corresponding grooves in adjacent pieces and filling them with a slip tongue, or spline, is generally employed for plank flooring.

A grooved, tongued-and-mitered joint, shown in (*f*), possesses the qualities of strength and effectiveness, and no edge grain is exposed.

The half-lap dovetail joint, shown in (*g*), is a form in which the dovetails appear only on one side, and is the method adopted for drawer fronts.

The lapped-and-tongued miter joint, shown in (*h*), is somewhat similar to the joint shown in (*f*), but a slip tongue is inserted instead of being worked out of the solid material.

A lapped miter joint, shown in (*i*), is made by rabbeting and mitering the boards to be joined, and securing them with nails.

A miter-and-butt joint, shown in (*j*), is a good form for an angle joint and is simpler than the joint shown in (*i*).

A miter-keyed joint is a miter strengthened by a slip feather, as in (*k*), or with slips of hardwood fitted into saw kerfs, as in (*l*).

A rabbeted joint, shown in (*m*), is formed by cutting rectangular slips out of the edges of the boards to a depth generally

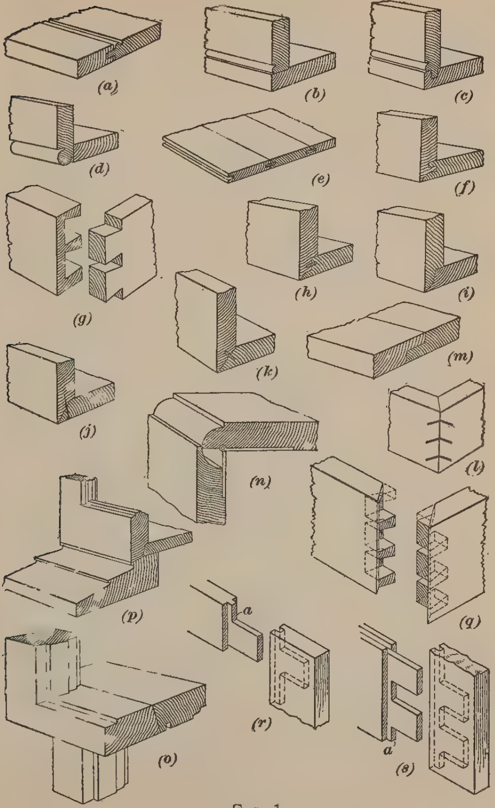


FIG. 1

equal to one-half of their thickness, the tongues thus formed being lapped over each other.

A rule joint, shown in (*n*), is a hinged joint used for the leaves of tables, etc.

Beveled joints, shown in (*o*) and (*p*), are formed to close tightly and exclude the wind and water.

The blind dovetail joint, shown in (*q*), used for boxes and cabinets where the dovetails are not to show, is made by dovetailing three-fourths of the thickness of the board and mitering the other fourth.

Mortise-and-tenon joints, shown in (*r*), and double-tenoned joints, shown in (*s*), are used in framing doors together. The parts *a* are called haunches.

DOORS

Proportions.—The ratio between the width and height of doors at main entrances and in public buildings is usually as 1 to 2; that is, the height is twice the width. For single doors in dwellings and offices, the ratio should be as 1 to 2½; or the height should be 2½ times the width; doors 2′ 8″×6′ 8″ and 3′×7′ 6″, are thus proportioned.

The width of a door is regulated by the purpose for which it is intended: in public buildings, provision is made for the passage of several persons at a time; in private houses and offices, a width suitable for one person is sufficient. In the former case, the width may be from 6 to 14 ft., while in the latter, the general rule makes the minimum width 2 ft. 8 in. for communicating doors, and 2 ft. for closet doors. A hinged door more than 4 ft. wide should be made double; that is, in two folds. As double folding doors take up considerable wall space when kept open, sliding doors are frequently substituted. Where there are several doors of different widths in the same room, to give a better effect to the interior treatment the height of the principal doors should be fixed by the proportion given, and the others made the same height. If the width of double or sliding doors does not exeed 6 ft., the height may be that of principal doors, but if wider, the height should be one-fourth more than the width. The width of sliding doors, however, is largely regulated by the depth obtainable for the pocket in the partition.

The width of the stiles and top rail should be about one-seventh the width of the door, the bottom rail about one-tenth the height, and the muntins and lock-rails ½ in. less in width than the stiles. The thickness will depend somewhat on the size, the style of finish, and the class of lock to be used. If the door framing is solid and rim locks are used, the thickness for chamber doors may be 1¼ in.; if mortise locks are used, the thickness should not be less than 1½ in. Solid doors for principal rooms are made from 1¾ in. to 2 in., and entrance and vestibule doors from 2½ in. to 2½ in. thick. When doors are veneered, the thickness is usually increased ¼ in.

When mortise locks are used the doors should, for strength, be framed with a lock panel so that the joints adjacent to the lock will not be injured.

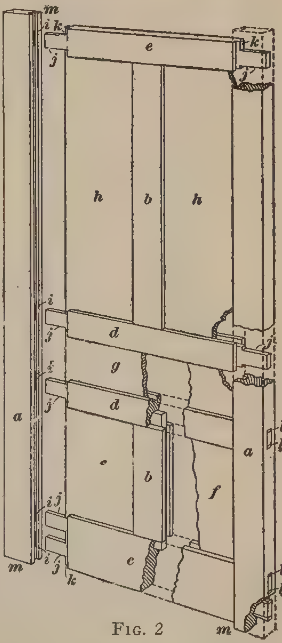


FIG. 2

Mortise-and-Tenon Doors.—The mode of constructing a five-paneled solid door is shown in Fig. 2, the moldings and certain parts being removed to show clearly the joints. The parts marked *a* are the outer stiles; *b*, the muntins; *c*, the bottom rail; *d*, the lock-rails; *e*, the top rail; *f*, the lower panels; *g*, the lock-panel, and *h*, the upper panels. The mortises *i* are made one-third the thickness of the framing into which the tenons *j* are fitted. The edges of the framing are grooved ½ in. deep, to receive the panels, the width of the groove being the same as the thickness of the tenon. The upper edge of the tenons of the top rail and the lower edge of the tenons of the bottom rail are haunched, as shown at *k*. The bottom rail has double tenons with a bridge between the mortises. The muntins are mortised into the rails. The panels should be kept from ⅛ to 3/16 in. less than the width of the space between grooves, to permit expansion.

In putting the door together, only the shoulder, or that portion of the tenon next the panel, should be glued, so that in case of shrinkage or swelling the joints will remain close. When the stiles are driven up and the clamps applied, the wedges *l* should be well fitted, should have the edges next the tenons brushed with glue, and be driven in tightly. The horns *m*, or extra lengths of the stiles during construction, are designed to withstand the pressure exerted when the end wedges are driven in. These would otherwise be forced out by shearing the fibers of the wood beyond the mortise, thus destroying the joint.

Dowel Doors.—Stock doors are usually made with dowels, as shown in Fig. 3, instead of with tenons. The rails can be made of shorter lengths.

Built-up Doors.—When a better grade of door is desired, it is built up as shown in Fig. 4, which is a section of the stiles and rails around the outer edges of the door. These stiles and rails are built up of several strips of clear white pine ⅞ in. thick, glued together, which form the core. The outer edges of the door are covered with a ⅞-in. strip *e* of the same wood that is used for veneering the door. The thickness of this strip permits of planing the edges of the door so that it may fit into the jambs, without exposing the pine core. The veneer *d* is ⅛ in. to ¼ in. thick and is glued to the core. Strips of wood *b* are glued into the cores of all rails, stiles, and muntins to provide proper bearings for the moldings *c*, which are glued or nailed to them. The panels *f* should be built up of five plies of veneering, each layer having its grain at right angles to that of the adjacent layer. The panels are made slightly smaller than the space enclosed by the strips and should not be nailed or glued in place but left free to swell or shrink. Panels should be filled and varnished, or painted before being set in place, or they may shrink later on and show edges of unfinished wood.

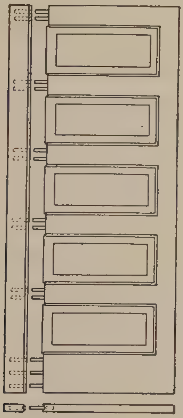


Fig. 3

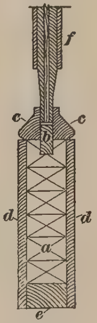


Fig. 4

Certain firms make a specialty of manufacturing patented built-up doors. The patents apply to the method of interlocking or dove-tailing the strips of the core together and of dovetailing the veneer to the core, thus increasing the glue surfaces and preventing the veneer from peeling. These doors are made in great quantities and it is often advantageous to order a certain make of door in building a house.

Doors, whether solid or veneered, should not be exposed to dampness, nor should they be hung or stored in a building where the plaster has not thoroughly dried out. Veneered doors should not be used as outside doors unless well protected by a porch or piazza. Veneered doors should be filled or painted as soon as they arrive at the building.

Outside Door and Frame in Masonry Wall.—In Fig. 5 (*j*) is shown a detail drawing of a door and door frame in a masonry wall. The frame *a* which is generally set when the building is nearly finished, is made somewhat smaller than the masonry opening. It is then blocked with rough lumber or studs *b*, which are securely fastened to the wall and support the frame.

The frame is double-rabbeted to take the main door on the inside and a mosquito door on the outside. The staff bead *c* forms a finish for the corner and should be fitted tightly against the masonry jambs to make a weather-tight joint. It is frequently made with a quirk *d*, which conceals the joint with the masonry. The inside trim, or architrave, is shown at *e*. A transom sash, which is a common feature over outside doors, is shown at *f*; the transom bar *g* forms the head of the door and the sill for the transom sash.

The door *h* is shown with heavily molded panels on the outside and with a lighter molding on the inside panels, which will correspond with the moldings of the interior doors. The outside moldings *i* are called raised moldings, as they project beyond the face of the door. The interior moldings *j* are called flush moldings because they do not project beyond the face of the door. The panel *k* is known as a raised panel on account of its having a raised face worked on it, whereas a plain panel is of uniform thickness throughout.

A drip mold *l* is set into the bottom rail of the door to protect the joint with the sill from wind and rain. The stone sill *m* has a saddle worked in it which projects above the floor level. Ordinary wooden saddles used with interior doors and exterior doors with wooden sills are shown in (*h*). A metal saddle is shown in (*i*).

Outside Door and Frame in Frame Wall.—In Fig. 5 (*a*) is shown a detail of an outside door and frame such as is used in a frame building. The frame *a* is rabbeted on the inner edge to receive the door and a rabbet is formed on the outer edge to receive a screen door by setting the outside architrave back

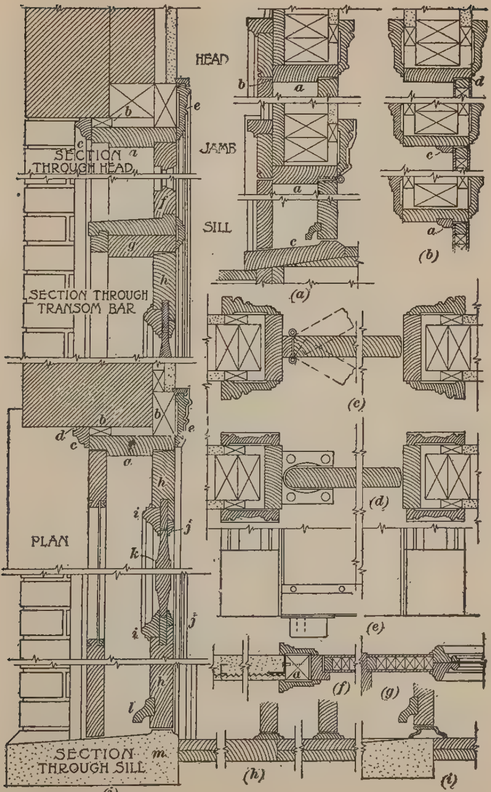

HEAD
JAMB
SILL
a
b
c
d
e
f
g
h
i
j
k
l
m
SECTION THROUGH HEAD
SECTION THROUGH TRANSOM BAR
PLAN
SECTION THROUGH SILL
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)

FIG. 5

from the face of the frame ½ in. as at *b*. The sill *c* is of wood and has a saddle worked on its inner edge.

In (*b*) are shown sections of frames for inside doors in 6-in. partitions. The stop *a* is let into the face of the jamb, and the stop *c* is nailed to the surface of the jamb, though it may be secured to the jamb by adjustable screws. At *d* the frame is shown with a rabbet worked in the jamb to take the door in the customary manner.

Double-Acting Doors.—In Fig. 5 (*c*) is a double-acting door and frame. The door is hung on double-acting spring hinges. In (*d*) is shown a double-acting door operated by a double-acting spring floor hinge, which is let into the floor as shown in (*e*). At the top of the door, a plain pivot is used.

Doors in 2-In. Partition.—A method of trimming a door in a 2-in., solid, plaster partition is detailed in Fig. 5 (*f*). The buck or rough frame *a*, is fastened to the angle iron uprights of the partition and the door frame is secured to the buck.

Doors With Glass Panels.—In Fig. 5 (*g*) is detailed a section through the side rail of a door with a glass panel surrounded by a raised molding. The molding is divided on one side of the door and the glass is held in position by nailing the small portion of the molding in place.

Sliding Doors.—Sliding doors differ from ordinary doors chiefly in the method of hanging them. Generally they are hung with overhead hangers, which are secured to the top of the door and run on a single steel track. Sometimes, they are hung on adjustable hangers, with roller or ball bearings, that run in tubular tracks, as shown at *a*, Fig. 6. Frame partitions for sliding doors are from 10 in. to 13 in. in thickness, depending on the thickness of the doors and the sizes of the studs. If the partition is not a bearing partition, the studding at *b* and *c* may be 2 in. in thickness. If, however, the partition supports floorbeams or a partition above, the studding on one side of the partition is made 4 in. in thickness, as shown at *c*.

The pockets, into which the doors slide, should always be lined, as shown at *d*, so as to keep out dirt and plaster; they should also be provided with a back piece *k* against which the door may strike. The doors should be provided with rubbing strips *e*, which are applied to the four edges of the door on both sides, so that the door cannot rub against the stops. The stops *f* should be applied to the jambs and head and be adjustable. A special joint *g* is formed at the meeting stiles. The edge of one door is let into the edge of the other door so as to preserve the alinement of the doors when closed and so that there shall be no opening between them. A cast-iron guide *h* is screwed to the floor just inside the pocket and works in a slot

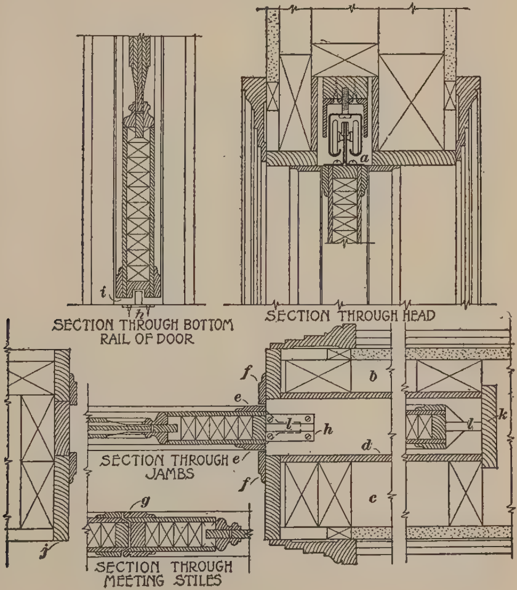

SECTION THROUGH BOTTOM RAIL OF DOOR
i
h
SECTION THROUGH HEAD
a
SECTION THROUGH JAMBS
f
e
b
l
h
d
k
l
e
f
c
g
j
SECTION THROUGH MEETING STILES

Fig. 6

formed in the bottom edge of the door *i*; this keeps the doors from swinging sidewise.

Sliding doors are usually designed in pairs, but a single door may be made to slide in the same manner as double doors when the jamb on the side opposite a single pocket is made as shown at *j*.

Fitting Doors.—The width of a swinging door should be about $\frac{3}{16}$ in. less than the width between the jambs, allowing a clearance of about $\frac{3}{32}$ in. on each side, and the opening edge should be slightly beveled. The standard bevel to which locks are made is $\frac{1}{8}$ in. in $2\frac{1}{4}$ in., but where the door is narrow, it may require the lock-face beveled to as much as $\frac{1}{4}$ in. in 2 in., or even more. An equal clearance should be left at the upper rail, while the bottom rail may require from $\frac{1}{4}$ in. to $\frac{1}{2}$ in., in order that the door may swing clear of the floor covering. If saddles are used the door should clear the saddle by about $\frac{3}{32}$ in.

Butts.—A simple rule for finding the width of butt required for any door is as follows:

Rule.—*To twice the thickness of the door, less $\frac{1}{2}$ in., add the greatest amount of projection of any part of the door casing beyond the face line of the door (which is usually the base block).*

Thus, if a door is 2 in. thick, and the base block projects $1\frac{7}{8}$ in., the width of the butt will be 2 in. + 2 in. − $\frac{1}{2}$ in. + $1\frac{7}{8}$ in. = $5\frac{3}{8}$ in., in which case a $5\frac{1}{2}$ in. width would be used. The edge of the butt will thus be kept $\frac{1}{4}$ in. back from the face of the door. One-half of the thickness of the butt should be cut out of the door, and one-half out of the jamb of the frame.

In locating the butts, it is usual to keep the lower end of the lower butt in line with the upper edge of the lower rail, while the top end of the upper butt may be kept from 6 to 7 in. below the upper edge of the top rail. Where three butts are used, it is well to keep the lower end of the intermediate butt in line with the upper edge of the lock-rail, instead of placing the butt midway between the upper and lower butts, as the butts will then line up with the framing. By keeping the pin of the lower butt slightly in advance of the upper butt, the door, in opening, will rise at the toe and increase the clearance, so that inequalities in the floor level may be overcome. For first-class working doors the following conditions must be observed: (1) The floor must be level in every direction. (2) Both jambs of the door frame must be accurately plumbed, facewise and edgewise, else the toe of the door will either rise above or fall toward the floor when operated. (3) The head-jamb, or transom, as the case may be, must be level. (4) The butts must be of good quality, well-fitted, and the pins kept true to line.

TRIM

The finish of doors and windows is called the trim, casings, or architraves. The simplest form of casing consists of a board 4 to 6 in. in width and mitered around the opening. The finish of doors and windows is capable of very elaborate treatment in which columns, pilasters, cornices, and pediments are used and in which elaborate carving may be employed. A few casings are shown in Fig. 7.

The casings shown in (*a*), (*b*), and (*c*) are used for mitered effects such as are shown in (*f*) and (*i*). In (*a*) the casing is made of a single strip of wood and the back is plowed out in order to prevent warping and twisting. The trim of a door is generally set back from the face of the door frame about $\frac{1}{4}$ in., as at *a*, so that the butt, or hinge, when let into the face of the jamb will not cut through the trim.

In (*b*) is a casing that is built up of three pieces, the piece *a* being called the back band. The flat member of the trim is let into the back band and a molding is planted in the corner. This construction permits the use of thin stock in making the trim, which is an economy, and the wood is not apt to curl or warp.

In (*c*) a similar trim is shown having a back molding set against the back band and scribed against the face of the plaster. The back molding is often carried around the trim of a door or window and across the top of the chair rail, base or wainscoting.

Casings, sometimes called pilaster casings, are shown in (*d*) and (*e*). They are generally used with corner blocks, as shown in (*g*). The casings are butted against the blocks and

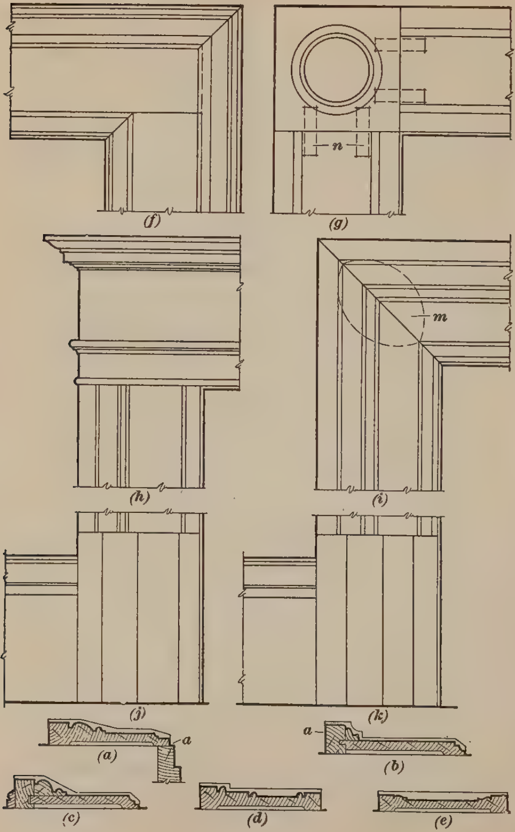


FIG. 7

are sometimes joined together by means of round dowels glued in, as shown at *n*.

Mitered casings made of one strip of wood are generally mitered together as shown in (*i*). A hardwood spline, or tongue, *m* should be inserted into grooves cut in the ends of the casings by a circular saw. The spline should be set with the grain at right angles to the miter cut and glued in place. When the trim is built up of two or three pieces, as in (*b*) or (*c*), the joint is best made by butting the flat face of the casing and mitering the moldings as in (*f*). This method of joining casings prevents the opening up of the joint due to shrinkage, which is so common with plain mitered joints.

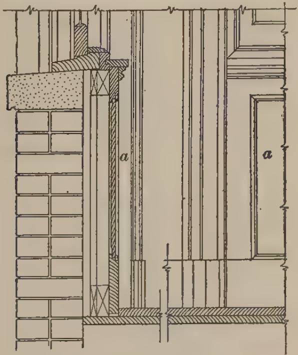


FIG. 8

Among other forms of casings, or trim, is that shown in (*h*), which consists of pilaster casings on the sides of the opening and a simple form of entablature over the head. This entablature is formed of a plain board with a small mold bradded or glued to the face and a small cornice molding mitered around the top. This form of trim is known as a cabinet trim.

In the details of windows previously given are shown examples of window finishes. Where the wall is thin, the casing is stopped on a stool with an apron and bed mold below. Where the wall is thick, as in masonry walls, jamb casings are required to fill the space between the box and the face of the plaster. When the casings are carried to the tops of plinth blocks, the trim is like that of a door.

Where the wall is very thick, the part under the window frame and between the jambs of the masonry opening is sometimes made thinner and the recessed surface under the window frame is paneled as shown in Fig. 8. The jamb casings and the trim of the window extend to the floor. The paneled surface *a* is called a panel back.

Plinth blocks are placed at the bottoms of casings as shown in Fig. 7 (*j*) and (*k*). This treatment is generally used with door casings and with the casings of windows that are carried to the floor. The use of plinth blocks avoids the necessity of carrying the fine moldings of the casing to the floor, where they are apt to be filled with dirt, and provides a sufficient thickness of material to receive the base. Plinth blocks are usually shaped to match the profile of the casing, and in Fig. 7 the sections of casings in views (*a*), (*b*), etc. have profiles of plinth blocks shown on them.

BASES

Bases, base boards, or skirtings are boards fitted against the walls at their intersection with the floor. In closets and unimportant rooms, the base consists of a $\frac{7}{8}$-in. board with a simple molding on top, as in Fig. 9 (*a*). A quarter-round molding *b* is frequently fitted into the angle of the base and floor so as to conceal the crack that will appear if the base shrinks. Where there is a double floor, the base is set before the finished floor is put in place and the floor is fitted against the base as shown in (*a*), (*b*), and (*c*).

In (*b*) is shown a more elaborate base formed of a molded board with a rich molding rabbeted on top. A still more elaborate base, consisting of three pieces, is shown in (*c*). Suitable grounds are shown for nailing these various bases in place. The base is sometimes sawed lengthwise through about one-half of its thickness, as shown at *a* in (*b*), to prevent warping and twisting. Housekeepers object to bases with projecting moldings as they catch dust; it is therefore desirable that the moldings should have as slight projections as possible.

CHAIR RAIL

A molded band, or chair rail, *a*, Fig. 10, is sometimes applied to plastered walls to prevent the backs of chairs from marring the plastering or papering. It should be about 4 in. or 5 in. in width and should be placed about 3 ft. above the floor; the projection should be less than that of the door and window casings against which it runs. Suitable grounds *b* should be provided for nailing the chair rail to the wall.

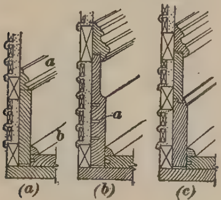


Fig. 9

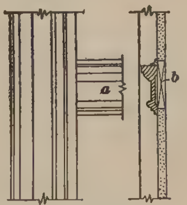


Fig. 10

WAINSCOTING

The wall is sometimes covered for its whole height, but more often to the height of 3 ft. or 4 ft., with a wainscoting. This wainscoting may be made of marble or wood and in its simplest form consists of matched boarding crowned with a simple cap mold, Fig. 12. The matched boarding may have a V-joint as shown in Fig. 11 (*a*); a beaded joint as in (*b*); or a molded face like that shown in (*c*). This boarding, which is also called ceiling, is nailed to grounds by blind nailing in the same manner as flooring. By other treatments of the faces of the boards, various interesting effects may be obtained. A cap mold *a*, Fig. 12, is always placed on top of the boarding and is scribed to fit closely against the plaster wall. The cap should not, as a rule, project beyond the casing. A base *c*, *d* is sometimes run around the bottom.

Paneled wainscoting should be constructed with the same care as is used in making doors. In the best work the rails and stiles are veneered and the panels made up of five thicknesses of veneer. The panels are glued up with the grain of one layer at right angles to the grain of the next layer. Paneled wainscoting should be put together at the shop and brought to the building in lengths ready to fit into position. Fig. 13 shows a detail of a paneled wainscoting with the cap *a* and a small molding *b* let in to form a frieze. At *c* is a rail, at *d* the stiles, and at *e* the bottom rail with a base *f*. The panels should be put in, as shown in Fig. 14. The molding *a* is glued to the stile, or rail *b*, which is rabbeted to receive it. The panel, having been filled and varnished or painted, is set in from the back and secured in place by means of strips of wood nailed to the stile. The panels should not be glued or nailed in place, but left free to swell or shrink. The plastering behind the wainscoting should be kept free from the wainscoting. This is accomplished by omitting the finishing coat and sometimes the brown coat of plastering.

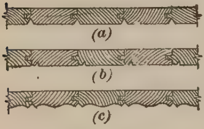
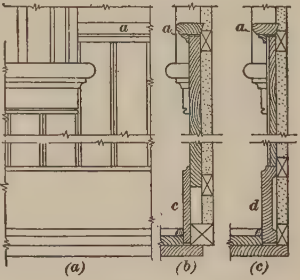

(*a*)
(*b*)
(*c*)

FIG. 11



(*a*) (*b*) (*c*)

FIG. 12

INSIDE CORNICES AND PICTURE MOLDINGS

Cornices of wood, such as are shown at *a* Fig. 15, are frequently used. Where false beams, such as shown at *b*, are used, they are so designed that the lines of the moldings will

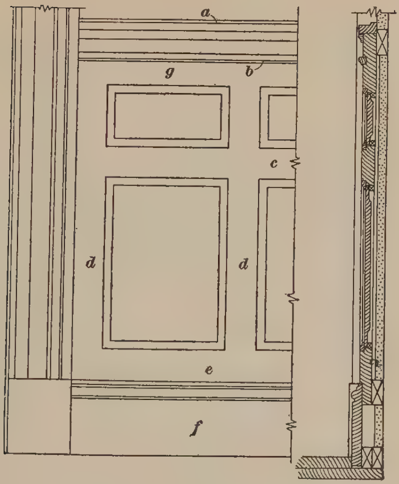


FIG. 13

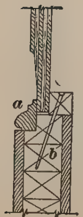


FIG. 14

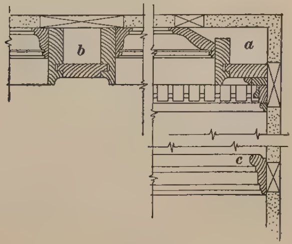


FIG. 15

correspond with the lines of the cornice and will miter or can be coped together.

A picture molding is shown at *c*, which is one of a number of forms that are made.

MANTELS

Mantels may be especially designed or selected from the catalogs of manufacturers. They are made of wood, marble, stone, and imitation stone. Wood mantels are made of the same wood and finish as the trim of the room, and may be of hardwood with natural finish or of soft wood painted or enameled. Marble and stone are used for expensive mantels in which carving is employed; field stone is used where a rustic effect is desired. Mantels modeled after fine examples are cast in artificial stone and are shown in the manufacturers' catalogs.

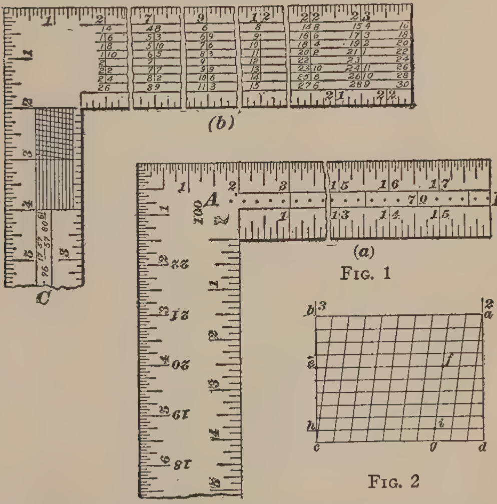
STEEL SQUARE

DESCRIPTION

The standard steel square is shown in Fig. 1 and consists of two parts: the blade or body, which is generally 24 in. long and 2 in. wide; and the tongue, which is usually 18 in. long and $1\frac{1}{2}$ in. wide. The outside edges on one face are divided into inches and sixteenths, and on the other face the inches are divided into twelfths. On the inside edge, the graduations are to eighth inches on one side and to thirty-seconds on the other.

On the tongue, near its junction with the blade, Fig. 1 (*b*), is a diagonal scale (shown enlarged in Fig. 2), used for taking off hundredths of an inch. The line *ab* is here 1 in. long, and is divided into 10 parts; the line *cd* being also divided into 10 parts, diagonal lines are drawn connecting the points of division as shown. For example, to take off .76 in., count off seven spaces from *c*, *cg* equaling .70 in.; now count up the diagonal line until the sixth horizontal line *ef* is reached; then *ef* is equal to .76 in.

On the same side of the tongue is the brace scale *C*, Fig. 1 (*b*). This scale gives the length of a brace of given rise and run, or, in other words, the length of the hypotenuse of a right-angled triangle with equal sides. For instance, the hypotenuse of a triangle each of whose sides is 57 in., is 80.61 in. The length and end cuts for a brace of any rise and run may be found by using the square in a similar manner.



(*b*)

(*a*)

FIG. 1

FIG. 2

On the blade, Fig. 1 (*b*), is shown the board-measure scale, the use of which will be explained by aid of an example. Let it be required to find the number of board feet in a 1″×7″ board, 13 ft. long. Under the 12-in. mark, find the number 13, and follow the horizontal space in which 13 is found to the 7-in. mark; the answer is there found to be $7\frac{7}{12}$ ft. B. M. If the board is over 1 in. thick, the problem is solved in the same way, the result being multiplied by the thickness in inches. If the length of the board is greater than any number given under the figure 12, it should be divided into parts, as in the following example: Required the contents in board measure of a 2″×9″ plank, 23 ft. long. Divide the length into two parts, 10 ft. and 13 ft.; the contents of the 10-ft. part is found, as before shown, to be $7\frac{6}{12}$ ft. B. M.; that of the 13-ft. board, is found to be $9\frac{9}{12}$ ft. B. M. Therefore, the total contents (if 1 in. thick) is $7\frac{6}{12}+9\frac{9}{12}=17\frac{3}{12}$ ft. B. M.; but as the board is 2 in. thick, the contents are $2\times17\frac{3}{12}=34\frac{1}{2}$ ft. B. M.

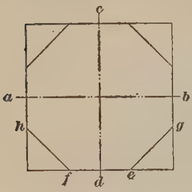


FIG. 3

The octagonal scale, found on the tongue at *AB*, Fig. 1 (*a*), is used in inscribing an octagon in a square. The scale is marked 10, 20, 30, etc. To inscribe an octagon in a 12-in. square (see Fig. 3), draw the lines *ab* and *cd*, bisecting the sides; from *d* mark *de* and *df*, each equal to twelve divisions on the octagonal scale; mark *bg*, etc., in the same way, and draw *eg*, a side of the required octagon. The other sides may be similarly found. For a 10-in. square, make *de* equal to ten divisions; for a 7-in. square, equal to 7 divisions, etc.

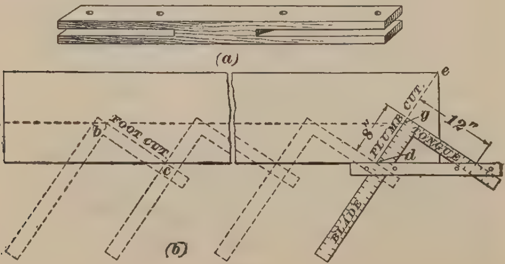


FIG. 4

In Fig. 4 (*a*) is shown an adjustable fence, a strip of hardwood about 2 in. wide, 1½ in. thick, and 2½ ft. long. A saw kerf, into which the square will slide, is cut from both ends, leaving about 8 in. of solid wood near the middle. The tool is clamped to the square by means of screws at convenient points, as shown. Let it be required to lay out a rafter of 8 ft. rise and 12 ft. run. Set the fence at the 8-in. mark on the blade, and at the 12-in. mark on the tongue, clamping it to the square with 1¼-in. screws. Applying the square and fence at the upper end of the rafter, gives the plumb-cut *de* at once. By applying the square, as shown, twelve times successively, the required length of the rafter and the foot-cut *cb* are obtained. In this case the twelve applications of the square are made between the points *c* and *d*. Run and rise must also be measured between these points. If run is measured from the point *b*, which will be the outer edge of the wall plate, it will be necessary to run a gage line through *b* parallel to the edge of the rafter, and subtract a distance *eg* from the height of the ridge, to give the correct rise. The square must then be applied to the line *bg*. A rafter of any desired rise and run may be laid off in this manner by selecting proportional parts of the rise and run for the blade and tongue of the square. For a half-pitch roof, use 12 in. on both tongue and blade; for a quarter-pitch, use 6 in. and 12 in.; for a third-pitch, use 8 in. and 12 in., etc.

USE OF STEEL SQUARE IN ROOF FRAMING

INTRODUCTION

In treating of the uses of the steel square, special consideration should be given to its usefulness in roof framing, to which class of work it seems particularly adapted. The several members of the roof will be considered separately, showing in each case the more common methods of obtaining the lengths as well as the cuts by the use of the steel square. These methods are applicable to a true hip roof, that is, one in which the hip or valley lies at 45° with the plates when shown in plan.

The constant 1.4142 plays a very important part in laying out roof framing. For instance, if the diagonal of 12 in. and 12 in. is 1.4142 ft. or 16.97+in., the diagonal of any other equal distances at right angles may be found by multiplying one side by 1.4142, if the measurement is in feet, and by 16.97 if it is expressed in inches. The figure 17, however, is here used instead of 16.97. This may be better understood by referring to Fig. 1, where *ABCD* represents the end of a hip roof 24 in. wide. When the run of the hip *EB* is revolved into the plane of the common rafter *EA*, the distance *EF* will be 16.97 in. or practically 17 in.

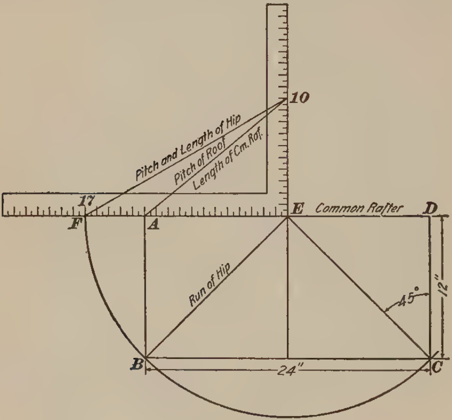


Fig. 1

COMMON RAFTERS

Finding Length of Common Rafters.—The length of common rafters for shed, gable, hip and valley roofs may be found by the following methods:

First Method.—Multiply the diagonal, or bridge, measure of 12 in. and the rise per foot of run of the common rafter, in inches, by the run of the common rafter, in feet. For example, in a $\frac{5}{12}$-pitch roof, that is one having a rise of 10 in. in 12 in. and a 20-ft. span, the run of the common rafter is 10 ft. The bridge measure of 10 in. and 12 in. is 15.62 in. The length of the rafter is therefore $15.62 \times 10 = 156.2$ in., or practically 13 ft. If a 2-in. ridge board is used multiply 15.62 by $9\frac{11}{12}$.

Second Method.—Lay off the total run on the blade of the square and the total rise on the tongue of the square, considering the feet as inches. Measure the diagonal, or bridge measure, in inches and read it as in feet. Thus, illustrating with the same $\frac{5}{12}$-pitch roof, the total run is 10 ft., and the total rise is 100 in., or $8\frac{4}{12}$ ft. The bridge measure of 10 in. and $8\frac{4}{12}$ in. is 13 in. Therefore, the length is 13 ft.

If the ridge board is 2 in. thick, a portion of the rafter equal to one-half the thickness must be cut off. In practice, instead of making the two-cuts at the top of the rafter, allowance is made for the ridge board and the rafter is cut to the proper length by one cut.

Cuts for Common Rafters.—The cuts for common rafters are found by the following methods:

First Method.—To obtain the foot-cut, or cut at the foot of the rafter, take 12 in. on the body of the square and the rise in inches per foot of run on the tongue. Lay the square on the rafter with these marks on the upper edge and with the 12-in. mark at the lower end of the rafter. Cut along the body of the square.

To obtain the plumb-cut, move the square so that the mark on the tongue is at the upper end of the rafter and cut along the tongue of the square.

Second Method.—Take the total run and rise of the rafter. in feet, and consider them as in inches on the square and proceed as in the first method.

HIP AND VALLEY RAFTERS

Finding Length of Hip and Valley Rafters.—The lengths of hip and valley rafters may be obtained by any of the following methods:

First Method.—Multiply the bridge measure of 17 in. and the rise per foot run of the common rafter, in inches, by the run of the common rafter, in feet. For example, take the case of the roof already considered. Laying off 17 in. on the body of the square and 10 in. on the tongue, the bridge measure will be 19.7 in. The length of the hip or valley rafter is then 19.7×10=197 in., or 16 ft. 5 in.

Second Method.—The length may be found by taking the diagonal of the run of the hip or valley and the total rise. The run of the hip is obtained by taking the run of the common rafter on both the tongue and the body of the square, and measuring the diagonal. For example, calling the feet inches, lay off 10 in. on the tongue and 10 in. on the body of the square. Measuring the diagonal and calling the inches feet, the result is $14\frac{2}{12}$ ft. nearly, which is the run of the hip or valley. Again considering the feet as inches, lay off on the body of the square $14\frac{2}{12}$ in. for the run and on the tongue $8\frac{4}{12}$ in. for the rise. Measure off the diagonal, read the inches as feet and the result will be 16 ft. 5 in., the length of the rafter.

A more accurate method of finding the run of a hip or valley rafter is to multiply the run of the common rafter by 1.4142 which gives 10×1.4142=14.142 ft. or 14 ft. 1.7 in.

Third Method.—Another method of finding the length of these rafters is to use 17 on the tongue of the square and the rise per foot run of the common rafter on the body and apply the square to the hip or valley rafter as many times as there are feet in the run of the common rafter.

Cuts for Hip and Valley Rafters.—To obtain the foot- and plumb-cuts on any hip or valley rafter take 17 in. on the body of the square and the rise per foot, in inches, of the common rafter on the tongue and proceed as described in the first method for cuts of common rafters.

The foot and plumb-cuts for hip rafters are obtained by using the total run and total rise of the hip, as shown in Fig. 2.

Fitting a Hip or Valley Rafter Close to Ridge.—In order to make a hip or valley rafter with a rectangular section fit close to the ridge, another cut besides the plumb-cut is required at the top. This cut is called the side cut of the hip or valley. In order to obtain this cut take 17 in. on the tongue of the square and the length per foot run on the body and cut along the body. For example, in the roof already considered, take 17 in. on the tongue and 19$\frac{8}{12}$ in. on the body, cutting along the body. A second method is to take the total run of the hip on the tongue and the total length of the hip on the body, considering the feet as inches and cut along the body.

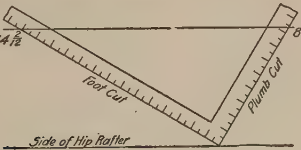


FIG. 2

When a hip or valley rafter is backed or has the upper corners dressed off so that the top edge will be in the same planes as the roof on both sides of the rafter, the cuts for the backing are found by taking the rise per foot run of the common rafter on the tongue and the length per foot run of the hip or valley on the body and cutting along the tongue. For example, take 10 in. on the tongue and 19$\frac{8}{12}$ in. on the body and cut along the tongue.

JACK-RAFTERS

Finding the Length of Jack-Rafters.—To find the difference in the lengths of jack-rafters, multiply the length, in feet, of the common rafter per foot of run, by the distance, in feet, between centers; subtract this product from the length of the common rafter, and it will give the length of the first jack-rafter, or the one next to the common rafter. For example, with a $\frac{5}{12}$-pitch, the length of the common rafter is 15.6 in. and the jack-rafters are spaced 2 ft. on centers. The first jack-rafter will be $2 \times 15.6 = 31.2$ in. shorter than the common rafter, the second jack-rafter will be 31.2 in. shorter than the first, etc. If spaced 16 in. on centers the difference in length will be $1\frac{4}{12} \times 15.6 = 20.8$ in. It follows that the run of the common rafter bears the same ratio to the length of the common rafter as the spacing does to the difference in length; that is, $10:13 = 2:2.6$, or $\frac{13 \times 2}{10} = 2.6$ ft. $= 2$ ft. $7\frac{2}{10}$ in. $= 31.2$ in. This same difference subtracted from the length of the first jack-rafter will give the length of the second jack-rafter.

Cuts for Jack-Rafters.—The foot- and plumb-cuts for jack-rafters are the same as the cuts for common rafters. Jack-rafters differ from common rafters, however, in that side, or cheek cuts are required at the tops in order to make them fit against the hip or valley rafters. In order to obtain this cut, take 12 in. of the run of the common rafter on the tongue and the length of the common rafter per foot of run on the body, and mark along the body on the upper edge of the jack-rafter. Saw through this mark and at the same time follow the plumb-cut on the side of the jack-rafter. Thus, take 12 in. on the tongue and 15.62 in. on the body of the square and mark along the body. Then cut as described.

ROOF BOARDS

As the roof boards are at right angles to the jack-rafters, the face cut will be the same as the check cut of the jack-rafters, except that the cut is made along the tongue of the square. For the miter cut, or cut on the edge, take the length of the common rafter per foot of run on the tongue, and the rise per foot of run on the body and cut along the body.

PURLINS

The miter and face cuts for purlins are the same as for roof boards.

SHINGLES

The cut for shingles is the same as the cheek cut of the jack-rafters.

OCTAGONAL ROOF

The figure 13 is to the octagonal roof what the figure 17 is to the rectangular roof.

Common Rafters.—The length and foot- and plumb-cuts of common rafters are obtained in the same manner as described for pitch roofs.

Hip Rafters.—There are several methods of obtaining the lengths of the hips in an octagonal roof.

First Method.—Multiply the bridge measure of 13 in. and the rise per foot of run, in inches, of the common rafter by the total run, in feet, of the common rafter. For example, if the roof has a rise of 16 in. in 12 in., measure the bridge measure of 13 in. and 16 in., which is found to be $20\frac{7}{12}$ in. If the run of the common rafter is 10 ft., the total length of the hip will be $10\times 20\frac{7}{12}=205\frac{10}{12}$ in. = 17 ft. $1\frac{10}{12}$ in.

Second Method.—Add 1 in. to every foot of run of the common rafter. Take this distance on the tongue, and the total rise on the body, calling the feet inches, and obtain the bridge measure, calling the inches feet. For example, the run of common rafter is 10 ft., adding 1 in. to every foot gives 10 ft. 10 in. The total rise is 13 ft. 4 in. Considering these as inches and taking the bridge measure, the result is $17\frac{2}{12}$ in., nearly. Calling the inches feet, the length of the hip is 17 ft. 2 in.

Cuts of Hip Rafters.—The foot-cut is found by using 13 in. on the tongue and the rise of the common rafter per foot of run on the body and cutting along the tongue. The plumb-cut is obtained by taking 13 in. on the tongue and the length of the common rafter per foot of run on the body, and cutting along the body.

There are several ways of framing the tops of octagonal hips and the side cut therefore depends on the method used. When all the hip rafters meet at a point and are not backed, take 5.38 in., or $5\frac{3}{8}$ in. on the tongue of the square, and the length of hip per foot of run on the body and cut along the body. When the hips are backed, take 4.97 in., or 5 in. on the tongue and the length of the common rafter per foot of run on the body and cut along the body.

When the upper ends of two hips butt together and the two hips at right angles to these butt against their sides, these four hips have square cuts on the top. The other four hips are framed into the angles formed by the first four and have cheek cuts on both sides. To obtain these cheek cuts when the hips are not backed, take 13 in. on the tongue of the square and the length of the hip per foot of run on the body and cut along the body. When the hips are backed, take 5 in. on the tongue and the length of the common rafter per foot of run on the body and mark along the body; then apply the square to this mark, using the same figures and cut along the body.

Jack-Rafters.—To obtain the difference in lengths of jack-rafters in any octagonal roof use the following proportions: 5, or 4.97 in. is to the length of the common rafter per foot of run, as the spacing, in inches, is to the difference in length. Thus, the length of the common rafter per foot of run in a 16-in. pitch is 20 in. If the jack-rafters are spaced 16 in. on centers, the difference in length will be, 4.97:20 = 16:64.4. That is, the first jack-rafter next to the common rafter will be 64.4 in. shorter than the common rafter, the second jack-rafter will be 64.4 in. shorter than the first jack-rafter, and so on.

Another method of obtaining this difference is to multiply the length of the common rafter per foot of run by .201 and then by the spacing in inches. Thus, $20 \times .201 \times 16 = 64.32$ in.

The foot- and plumb-cuts are the same as for the common rafter.

The side cut is found by taking 5 in. on the tongue of the square and the length of the common rafter per foot of run on the body and cutting along the body.

ROOFING

BUILT-UP ROOFS

Laid on Boards.—Built-up roofs are roofs made with slag or gravel laid on several layers of felt cemented together by means of pitch or asphalt. They may be laid on a concrete surface or on boards. If laid on boards, the boards should be tongued-and-grooved and should be planed to an even thickness. The first layer consists of one thickness of sheathing paper or unsaturated felt, weighing not less than 5 lb. per 100 sq. ft., put on with a lap of 2 in. The second layer is formed of two thicknesses of felt saturated with coal-tar pitch and weighing not less than 14 lb. per 100 sq. ft., each sheet lapping over the lower one 17 in. and being nailed as often as necessary to keep it in place. The third layer is a coating of coal-tar pitch thoroughly mopped over the entire surface. The fourth layer is composed of three plies of saturated felt, of the same kind and weight as that used in the second layer, laid in pitch, each layer lapping the one beneath 22 in. Nailing should be done when necessary, the nail heads being covered by at least two thicknesses of felt. The fifth layer is formed by mopping the entire surface with an even coating of coal-tar pitch and imbedding in it gravel or slag, using about 400 lb. of gravel or 300 lb. of slag for each 100 sq. ft. of surface. The weight of a roof made as above described is from 6 to 7 lb. per square foot and should last from 15 to 20 yr.

Laid on Concrete.—When a built-up roof is to be laid upon a concrete or cement surface, the first layer should be of coal-tar pitch mopped on uniformly. The second layer should consist of two thicknesses of saturated felt laid in pitch with a a 17 in. lap. The remaining layers are the same as for the roof on boards.

The roof on concrete is often finished with flat tiles or brick in place of the slag or gravel and may be set either in a bed o portland-cement mortar or in pitch.

Asphalt may be used in place of coal tar pitch for saturating the felt and for mopping the roof.

Ready Roofings.—Ready roofings, consisting of two or three layers of felt and burlap cemented together with coal-tar pitch or asphalt, and sometimes covered with grit or gravel, are sold in rolls, each roll containing enough material to cover an area of 100 sq. ft. Accompanying the rolls are the necessary accessories, such as nails and cementing materials. These roofings are easily applied and form a serviceable roof for sheds and outhouses.

Flashings used in connection with built-up roofing should be of copper, galvanized iron, or tin.

SHINGLES

Description.—The best shingles are made of cypress, redwood, and cedar. They are ordinarily 16 in. and 18 in. in length, but are sometimes made as long as 27 in. or 30 in. Common shingles are made in random widths varying from $2\frac{1}{2}$ in. to 14 in. The thickness at the butt, or thick end, varies from $\frac{7}{16}$ in. to $\frac{3}{10}$ in. and the thickness at the upper end is $\frac{7}{16}$ in. They are packed in bundles that contain the equivalent of 250 shingles 4 in. wide, and are sold at so much per 1,000 shingles or four bundles.

Dimension shingles are always cut to a uniform size or width, and are preferable in laying patterns; they are 4, 5, or 6 in. in width, and are usually dressed.

Shaved shingles are split and shaved with the drawknife but are difficult to obtain as shingles are generally sawed.

Clear butts indicate that the shingles contained in the bundle have a clear butt, or enough clear surface for the exposure to the weather.

Fancy butts, or pattern butts, are shingles having the butts, or ends, sawed to a geometric or other form, such as saw tooth, round, hexagonal, etc. These shingles are usually dressed.

Shingle lath, on which the shingles are laid, usually runs from $1\frac{1}{4}$ in.×2 in. to $1\frac{1}{4}$×3 in.

Valley, hip, and ridge boards are of either 1 in. or $1\frac{1}{4}$ in. in thickness, as required.

Methods of Laying.—The methods of laying shingles generally in use are: on shingle lath, on boarding without paper or felt, and on matched boarding and lath with felt. The first method is undoubtedly the best, though it is generally used on only cheap buildings. In more expensive houses, the requirements usually call for a matched-board roof. This method, however, prevents the free circulation of air under the shingles and causes them to decay quite rapidly.

The starting course of shingles should be doubled at the eaves and the ends should overlap the gutter about 1½ in. Each shingle is fastened with two fourpenny nails, and is exposed from 4½ in. to 5 in. on the roof and from 5 in. to 6 in. on the sides of the building.

Along the valleys *c*, Fig. 1, tilting fillets *a* should be placed over which the flashing *b* is formed. Similar tilting fillets should be placed along the upper edge of the gutter just above the overflow.

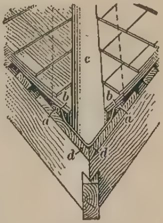


FIG. 1

Finding the Gage.—The gage or exposure to the weather of a shingle is obtained by subtracting the lap from the length and dividing the difference by 3. Thus, for a shingle 18 in. long, with a 3-in. lap, the exposed length will be 18 in. minus 3 in., or 15 in., which, divided by 3, will give 5 in.

The number of inches exposed to the weather multiplied by the average width of a shingle gives the area of the exposure; dividing 14,400 (the number of square inches in 100 sq. ft.) by the area of the exposure gives the number of shingles required to cover 100 sq. ft. of roof. For example, the average width of a shingle is 4 in., and if exposed to the weather 4 in., the area of exposure is 16 sq. in.; now, 14,400 sq. in. divided by 16 gives 900, which is the number of shingles required per square.

Number of Shingles Required.—The accompanying table is arranged for shingles from 16 to 27 in. in length, and is based on a given exposure to the weather. To these figures, 5 to 10% should be added for waste.

SHINGLES REQUIRED FOR ROOFING

Exposure to Weather Inches	Square Feet of Roof Covered by 1,000 Shingles		Shingles Required for 100 Sq. Ft. of Roof	
	4 In. Wide	6 In. Wide	4 In. Wide	6 In. Wide
4	111	167	900	600
5	139	208	720	480
6	167	250	600	400
7	194	291	514	343
8	222	333	450	300

Hips and Valleys.—Valleys are of two kinds as regards finish. The open valley is shown in Fig. 1. The shingles or slates are kept apart so that 8 or 10 in. of the metal, with which the valley is lined, is exposed. Before the shingling is begun, a long strip of metal *c* is laid on the boards *d* and over the tilting fillets *a*. The shingles are then laid as already described.

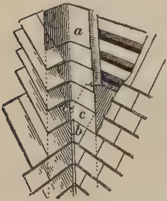


FIG. 2

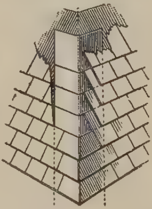


FIG. 3

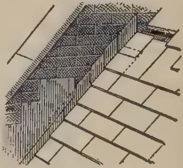


FIG. 4

In the close valley the shingles or slates almost meet as at *b*, Fig. 2, so that the metal flashings *a* and *c* do not show. The flashings consist of sheets of metal laid between the shingles as the work progresses.

The flashing of hips, as in Fig. 3, and the intersections of roofs with gable walls, as shown in Fig. 4, is done in the same manner as that of close valleys. The Boston hip, shown in Fig. 5, gives a very neat finish to the hip. Shingles of a uniform width of, say, 5 in., should be selected. A chalk line is snapped on each side of the hip, about 4½ in. from its center and parallel to it, as shown at *a*, Fig. 5. The slope shingles on the main roof should be carried up to this line, stepping back to allow the hips to be laid last. Lay the bottom shingles first with their edges at, and parallel to the hip line, and the lower corners of their butts just touching the butts of the shingles below, as shown. Across each hip shingle, and at right angles to the eaves, draw a line for the vertical side cut, as at *c*. Slightly taper the side *d* to secure a close fit at the intersection. Fit the hip shingle to the side of the main roof shingle, and nail in place as shown.

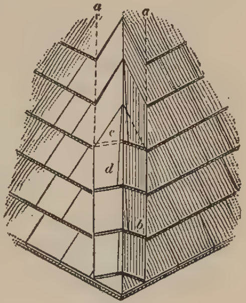


Fig. 5

One of the chief advantages of this method is that the grain of the wood runs with the hip, and the tendency to curl is taken away from the line of the hip to the side of the shingle.

SHEET-METAL ROOFS

TIN ROOFS

Roofing tin, or terne plates, are made of sheets of soft steel or iron-coated with tin or tin and lead. The sizes of sheets generally used are 14 in.×20 in. and 20 in.×28 in. The thickness of the plates is described by the signs IC, IX, etc. IC represents a plate of 30 gage and weighing about 10 oz. per sq. ft.; IX corresponds to 28 gage and weighs about 12 oz. per sq. ft. The gage is the United States standard. A box of tin plates contains 112 sheets. Measurements of tin roofing are based on a square of 100 sq. ft. The accompanying table shows the number of square feet of roof a box of tin plates will cover.

The cost of laying 14″×20″ plates will amount to about 25% more than the cost of laying 20″×28″ plates, because there are more cleats and seams, so that more solder and labor are required. Reliable brands of tin have the name of the manufacturer stamped on each sheet of tin.

Laying a Tin Roof.—If the tin is to be laid with a flat seam, or flat lock, the roof should have an inclination of ½ in. or more to 1 ft. run. If laid with standing seams, it should have an inclination of not less than 2 in. to the foot. A good pitch is desirable to prevent the accumulation of water and dirt in hollow places. Gutters, valleys, etc., should have a pitch sufficient to prevent water standing in them or backing up enough to reach standing seams.

ROOF AREA COVERED BY A BOX OF TIN PLATES

Size of Plates Inches	Thickness	Gage Number	Sheets in Box	Weight per Box Pounds	Square Feet of Flat Seam	Square Feet of Standing Seam	Weight per Square on Roof Pounds
14×20	*IC*	30	112	107	180	165	65
14×20	*IX*	28	112	135	180	165	82
20×28	*IC*	30	112	214	381	360	
20×28	*IX*	28	112	270	381	360	

Tin roofs should be laid on tongued-and-grooved sheathing boards, which should be of well-seasoned, dry lumber of narrow widths, free from holes, and of even thickness. A new tin roof should never be laid over old tin, shingle, or tar roofs. Sheathing paper is not necessary where the boarding is laid as just specified. If however, steam, fumes, or gases are likely to reach the under side of the tin, a good waterproof sheathing paper should be used under the tin. Tar paper should never be used.

Flat-Seam Tin Roofing.—Flat seams should be made as shown in Fig. 1 (*a*) to (*f*). When the sheets are laid singly, they should be fastened to the sheathing boards by cleats, Fig. 1 (*b*) and (*c*), using three cleats to each sheet, two on the long side and one on the short side. Two 1-in., barbed, wire nails should be used to each cleat, but nails should never be driven through the sheets. If the tin is put on in rolls, the sheets should be made up into long lengths in the shop, the cross-seams locked together and well soaked in solder. The rolls should be edged ½ in. and fastened to the roof boards with cleats spaced 8 in. apart, and locked into the seam. The cleats should be fastened to the boards with two 1-in., barbed, wire nails to each cleat, as shown in Fig. 1 (*c*).

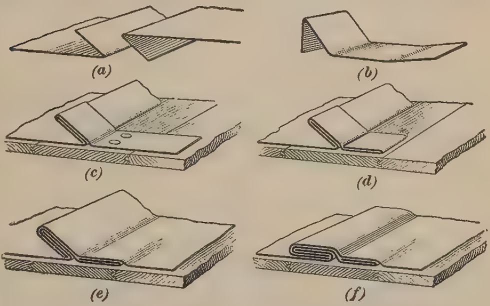


FIG. 1

Standing-Seam Tin Roofing.—The method of making standing seams is shown in Fig. 2 (*a*) to (*f*). For this kind of roofing, the sheets of tin should be put together in long lengths in the shop, the cross-seams locked together and well soaked with solder. The sheets should be applied to the roof the narrow way and fastened with cleats spaced 1 ft. apart. One edge of the strip is turned up 1¼ in. at right angles to the sheet and the cleats installed as shown in (*b*). The adjoining edge of the next course is turned up $1\frac{1}{2}$ in. as in (*c*) and these edges locked together, as shown in (*d*), turned over, as in (*e*), and the seam left, as shown in (*f*).

Valleys and gutters in all cases should be covered with IX tin and formed with flat seams, applying the sheets the narrow way. It is important that good solder be used, bearing the manufacturer's name and guaranteed to consist of one-half new tin and one-half new lead. Rosin should be used as a flux. The solder should be well sweated into all seams and joints.

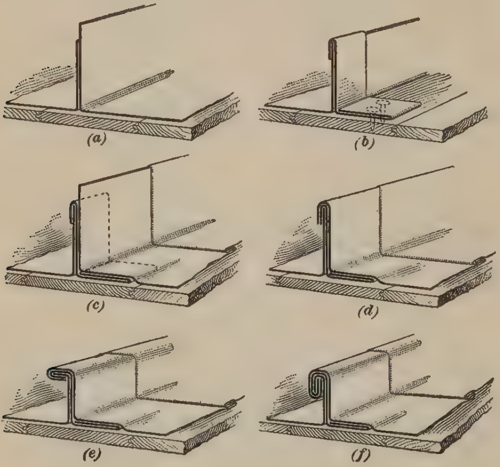


FIG. 2

Painting Tin Roofs.—All painting should be done by the roofer. The tin should be painted one coat on the under side before it is applied to the roof. The upper surface of the tin roof should be carefully cleaned of all rosin, dirt, etc. and immediately painted. The most approved paints for this purpose are metallic brown, Venetian red, red oxide, and red lead, mixed with pure linseed oil. No patent dryer or turpentine should be used. All the coats of paint should be applied with a hand brush and well rubbed on. A second coat of paint should be applied 2 wk. after the first. The third coat should be put on about 1 yr. later.

Caution.—All unnecessary walking on a tin roof should be avoided as well as storing building or other materials on it. The tin surface is easily scratched from the iron plates, which exposes these plates to corrosion. Workmen should wear rubber-soled shoes or overshoes when working on the roof.

Maintenance of Tin Roofs.—To keep a tin roof in good condition, it should be painted at intervals of from 3 to 5 yr., depending on the slope of the roof and on local conditions. The gutters should be kept free from deposits of dirt and leaves and painted more frequently.

COPPER ROOFS

Laying Copper Roofs.—The methods employed in laying copper roofs are usually the same as those required for tin roofing, although the flat roof laid with a lap seam is not to be recommended. It is weak, and, being soldered and nailed, will not permit sufficient expansion and contraction. Where solder is used, the lock-seam with cleats is best. The copper should be thoroughly tinned before commencing to solder it.

GAGE, THICKNESS, AND WEIGHT OF SHEET COPPER

Gage Number	Thickness Inch	Weight Ounces per Square Foot
29	.0134	10
27	.0161	12
26	.0188	14
24	.0215	16
23	.0242	18
22	.0269	20

The standing-seam method of laying should be employed where extra strength and stiffness are required, on very steep-pitched roofs, and on flat surfaces where work without solder is to be carried out. The gage, thickness, and weight per superficial foot of copper used for roofing purposes, are given in the accompanying table.

Copper Tiling.—Copper roofing tiles are made in imitation of most of the different forms of terra-cotta tiles. A common form of copper tile used is the imitation of the Spanish clay tile, as shown in Fig. 3.

For straight surfaces the following sizes of tiles are used: 7 in. × 10 in., 10 in. × 14 in., and 14 in. × 20 in. The last size is best adapted for large roofs, but for ordinary roofs 10 in. × 14 in. is the size recommended. These tiles may be made of 12-oz., 14-oz., or 16-oz. copper. A square will require four hundred 7″ × 10″ tiles; one hundred and seventy-four 10″ × 14″ tiles; or seventy-two 14″ × 20″ tiles. These quantities allow for laps, waste, cutting, etc. All flashing on copper roofs is done with copper.

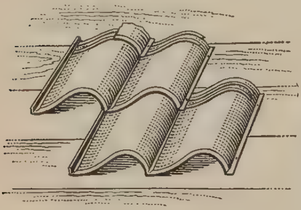


Fig. 3

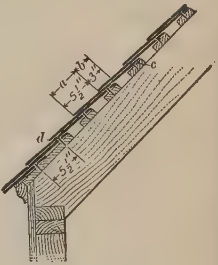


Fig. 4

SLATE ROOFS

Qualities of Slate.—Good slate should possess toughness, hardness, and a very fine, but easily distinguished, grain. The slates should be tough enough to be easily punched for nailing, and should cut to standard sizes without splintering or becoming friable at the edges. They should be hard enough not to absorb much moisture, as the action of frost on the moisture will cause the edges to crumble and will also tend to enlarge the nail holes, and thus cause the slate to loosen from the roof. The grain should run lengthwise of the slate. Veins or ribbons are objectionable markings, especially when parallel with the grain.

QUANTITY OF SLATE AND NAILS PER SQUARE OF ROOF

Sizes of Slates Inches	Number in Square	Exposed to Weather Inches	Distances on Centers of Lath Inches	Pounds of Nails Required		
				Kind	Pounds	Ounces
14×24	98	10½	10½	4-penny	1	6
12×24	115	10½	10½		1	10
12×22	126	9½	9½		1	12
11×22	138	9½	9½		1	15
12×20	142	8½	8½		2	0
10×20	170	8½	8½		2	6
12×18	160	7½	7½	3-penny	1	13
10×18	192	7½	7½		2	3
9×18	214	7½	7½		2	7
12×16	185	6½	6½		2	2
10×16	222	6½	6½		2	8
9×16	247	6½	6½		3	0
8×16	277	6½	6½		3	2
10×14	261	5½	5½		3	0
8×14	327	5½	5½		3	12
7×14	374	5½	5½		4	4
8×12	400	4½	4½		4	9
7×12	457	4½	4½		5	3
6×12	533	4½	4½		6	1

A good slate should present a bright, silk-like luster, and should emit a clear, metallic ring when struck with the knuckles, showing that it is hard; if it is soft, it will have a dull, lead-like surface, and will give out a muffled sound. When cut, the edges should show a fibrous-like texture, free from splinters, and the material should not show signs of being either brittle or crumbly. No better test of the wearing or weathering qualities can be applied than the simple and effective one of examining roofs where similar slate has been in service for several years.

Terms Used in Slating.—The terms applied to the different parts of roofing slate are: the gage, or weather, which is that part of the slate which is exposed when laid, as shown at *a*, in Fig. 4; the lap, which is the distance that each slate overlaps the second one below it, as at *b*; the head, or upper end of each slate, as at *c*; and the tail, or lower end of each slate, as at *d*. The bed is the under surface of each slate when laid, and the back is the upper surface when laid.

Sizes of Slate.—Slates are sold by the square, or number of slates that will cover 100 sq. ft. of the roof surface. The table on page 315 gives the sizes of slates, the number of pieces per square allowing a 3-in. lap, the exposure to the weather, and the number of pounds of nails required in laying the slates.

The thickness of standard slates varies from $\frac{1}{8}$ in. to $\frac{3}{8}$ in., the usual thickness being $\frac{3}{16}$ in. for slates of average size. Slates from 12 in. × 16 in. to 12 in. × 20 in. are most economical, as there are fewer pieces to lay than in the smaller sizes, and less loss from breakage than there would be in using the larger sizes. Slates should always be bored and countersunk at the quarry, instead of punched for nailing on the job. The accompanying table gives the weight of slate per square foot. The approximate weight of slate per square foot when laid upon the roof is $6\frac{1}{2}$ lb. for slate $\frac{3}{16}$ in. thick and $8\frac{3}{4}$ lb. for slate $\frac{1}{4}$ in. thick. The colors of slate are dark blue, blue-black, purple, red, and green.

WEIGHT OF SLATE PER SQUARE FOOT

Thickness Inch	Weight Pounds
$\frac{1}{8}$	1.82
$\frac{3}{16}$	2.73
$\frac{1}{4}$	3.64
$\frac{3}{8}$	5.46
$\frac{1}{2}$	7.28
$\frac{5}{8}$	9.06
$\frac{3}{4}$	10.87
1	14.50

Laying Slate.—Slates are laid on boards, covered with tarred or waterproofed paper, on wooden battens or laths, or on channel or angle iron purlins, as in fireproof buildings. The strips and angle irons are set a distance on centers equal to the exposed surface of the slate. The slates are nailed to the boards and battens with 3-penny or 4-penny slating nails, the best of which are made of copper and have broad heads. Slates are secured to iron framing by tying with copper wire or by means of special fasteners. In first-class work, the top course of slate on the ridge and the slates for 2 ft. to 4 ft. from all gutters and 1 ft. each way from all valleys and hips, are bedded in elastic cement.

Flashings for slate work may be of tin, zinc, or copper. The ridge is generally protected by a metal ridge roll lapped over the top of the slates. The hips and valleys should be protected by weaving in metal strips, as described under shingle roofs. The hips, however, are sometimes covered with metal hip rolls.

TILE ROOFS

The flat roofs of fireproof buildings are frequently covered with flat vitrified clay tiles, called Promenade tiles. These tiles are 6 in.×9 in.×$\frac{3}{4}$ in. or 1 in. in size and are put on over four or five plys of tarred felt laid in pitch on the concrete surface of the roof construction. They are bedded in a heavy coating of asphalt. The joints between the tiles should be not less than $\frac{3}{8}$ in. wide and be half-filled with asphalt; the upper half is then filled in with a strong cement grout.

For pitch roofs, tiles of various shapes are used, such as flat, Spanish or S-shaped tiles, and other special patterns. Suitable ridge rolls, hip rolls, crestings, and finials are made to be used with the various patterns of tiles, and are set in elastic cement or good portland cement mortar. Tiles should be burned until vitrified. The standard color is red, but other colors can be produced by glazing. Tiles made of clear glass are sometimes inserted in the roof at places where skylights would otherwise have to be used.

Tiles used on pitch roofs weigh from 750 to 1,200 lb. per square and should be laid on a tightly boarded roof upon which a layer of good roofing felt weighing 30 lb. per 100 sq. ft. has been laid. Each tile is nailed to the roof with two barbed, wire nails, preferably of copper.

Flashings used in connection with tile roofing should be of 16-oz. copper.

Cement roofing tiles are made of a mixture of portland cement, sand, and coloring matter reinforced with wire mesh. They are generally 22 in.×52 in. in size and $\frac{7}{8}$ in. thick, and weigh about 14 lb. per sq. ft. Special tiles have sheets of wire glass set in them, which afford light without the use of skylights.

ASBESTOS SHINGLES

Shingles made of cement and asbestos are used as roofing material. They are tough, strong, non-absorbent, fireproof, and light in weight. They can be obtained in a variety of sizes, 16 in.×16 in., 12 in.×12 in., 8 in.×8 in., 16 in.×8 in., 12 in.×6 in., and 4 in.×8 in. all of which are about $\frac{1}{8}$ in. thick. The butts are formed in various shapes, similar to those of shingles or slates. The weight of the shingles per square, laid in the French method, with 12″×12″ shingles is 272 lb. and 160 shingles are required. The weight of shingles per square laid in the American method, with 12″×12″ shingles is 432 lb. and 240 shingles are required.

CANVAS ROOFS

For the floors of sleeping balconies and for roofs that are to be walked upon, canvas roofs are used. The canvas, or duck, should be closely woven and treated with chemicals to preserve it from mildew and decay. The canvas should weigh about 16 oz. per sq. yd. and its width should be from 21 in. to 42 in. It should be tightly stretched with a lap of 1 in. and tacked to the roof boarding with heavy galvanized iron or copper tacks $\frac{3}{4}$ in. to $\frac{7}{8}$ in. long and spaced about $\frac{1}{2}$ in. apart, after which it should be wet and while still damp given a good coat of oil paint. It is then finished with two or three coats of paint.

ESTIMATING

APPROXIMATE ESTIMATES

The costs of buildings are frequently estimated at a unit price per cu. ft. of their contents. This price, however, is bound to vary considerably, due to the changing prices of labor and building materials, and to the varying nature of buildings. The prices given in the accompanying table must, therefore, be considered as approximate.

The cubical contents of a building are found by calculating the area of the largest floor, and multiplying this area by the height of the building from the cellar floor to the average height of the roof. If the roof is a gable roof, the height is taken to a point halfway between the attic floor and the ridge. Piazzas, porches, etc., are not generally included in estimating the cubic contents of a building. The cubic contents are found in cu. ft., and multiplied by an estimated cost per cu. ft. By keeping records of the costs of work already done, the contractor will be better able to estimate the price per cubic foot of new work.

COSTS OF BUILDINGS PER CUBIC FOOT

Class of Building	Cost
Frame dwellings, costing $20,000 or more..	$0.80 to $1.30
Schoolhouses, fireproof..................	.80 to 1.25
Churches..................................	.90 to 1.40
Hospitals.................................	1.00 to 1.25
Office buildings, fireproof................	1.00 to 1.25
Hotels....................................	1.25 to 1.50

ESTIMATES IN GENERAL

The amount of materials required for a given piece of work is fixed, and the cost of these materials will be based on the prices prevailing at the time of building. The labor cost can be calculated by assuming that the average mechanic will do a certain amount of work per hr. or day, then estimating the total time required for the work and multiplying this time in hours by the hourly rate of wages prevailing at the time. The total cost will be found by adding the costs of material and labor.

Suppose that 1,000 bd. ft. of flooring is to be laid. The cost of the flooring is $250. A carpenter will require 16 hr. to lay this flooring and will need a helper for 4 hr. The carpenter's wages are assumed to be $2.50 per hr., and helper's wages $2.00 per hr. The total cost of laying this flooring would then be estimated as follows:

Flooring, 1,000 board feet at $250.00 per M	$250.00
Carpenter, 16 hr. at $2.50 per hr	40.00
Helper, 4 hr. at $2.00 per hr	8.00
Total	$298.00

Overhead and Profit.—The prices given in the following pages are for the actual costs of the work to the contractor. No allowance has been made for overhead or profit. The overhead, or cost of doing the business of contracting, will vary from 5 to 20 per cent.

The profit which must also be added will amount to from 5 to 20 per cent., depending on the nature of the work, and the amount of office work and supervision required.

MASONRY

INTRODUCTION

Stone from the quarry is usually sold under two classifications, namely, *rubble* and *dimension stone.* Rubble consists of pieces of stone of irregular size, such as are most easily obtained from the quarry, varying from the small sizes to a maximum of 12 in. in thickness by 24 in. in length. Stone ordered of a certain size, or to square over 24 in. each way, and to be of a particular thickness, is dimension stone.

Stone walls are usually measured by the cu. yd. In some localities they are measured by the perch of about 25 cu. ft. The cubic contents are obtained without considering the openings. Deductions are then made for door, window, and other openings 10 sq. ft. or more in area. The measurements are taken on the outside of the wall, thus measuring the corners twice. This is done to offset the labor of plumbing and trimming the corners.

Ashlar work is always figured by the superficial foot. Openings are usually deducted, and the jambs are measured with the face work. Flagging and slabs of all kinds, such as hearths, treads for steps, etc., are measured by the sq. ft., while sills, lintels, moldings, belt-courses, and cornices are measured by the lin. ft. All carved work is done at an agreed price by the piece.

METHODS OF ESTIMATING MASONRY COSTS

The following are examples of estimating the cost of rubble masonry by the cu. yd. A small amount of Portland cement is generally added to lime mortar in order that the mortar may set rapidly. A small amount of slaked lime is usually added to cement mortar to make it work more smoothly. This applies to mortar for stone, brick, terra cotta, etc. The unit prices are approximate, and will vary in different localities.

Cost of Rubble Masonry Per Cubic Yard

Using 1-to-3 Lime Mortar Tempered With Cement

1 cu. yd. (27 cu. ft.) stone, delivered at work		$ 5.50
7 cu ft. mortar		
75 lb. lump lime at $1.40 per 100 lb.	$1.05	
25 lb. Portland cement at $5.40 per bbl.	0.36	
¼ cu. yd. sand at $4.55 per cu. yd.	1.14	
1 hr. laborer's time, mixing, at $2.00 per hr.	2.00	
	$4.55	4.55
3 hr. mason's time at $3.25 per hr.		9.75
3 hr. helper's time at $2.20 per hr.		6.60
Total cost per cu. yd.		$26.40

Cost of Rubble Masonry Per Cubic Yard

Using 1-to-3 Portland Cement Mortar Tempered With Lime

1 cu. yd. stone, delivered at job		$ 5.50
7 cu. ft. mortar		
½ bbl. Portland cement, at $5.40 per bbl.	$2.70	
8 lb. lump lime, at $1.40 per 100 lb.	0.11	
¼ cu. yd. sand, at $4.55 per cu. yd.	1.14	
1 hr. laborer's time, mixing, at $2.00 per hr.	2.00	
	$5.95	5.95
3 hr. mason's time, at $3.25 per hr.		9.75
3 hr. helper's time, at $2.20 per hr.		6.60
Total cost per cu. yd.		$27.80

Cost of Concrete Per Cubic Yard

1-2½-5, Hand Mixed

1¼ bbl. Portland cement at $5.40 per bbl.	$ 6.75
30 lb. hydrated lime at $34 per ton	0.51
½ cu. yd. sand at $4.55 per cu. yd.	2.28
1 cu. yd. broken stone	6.25
3¼ hr. laborer's time, mixing and placing, at $2.00 per hr.	6.50
Total cost per cu. yd.	$22.29

Cost of 1 Sq. Yd. of Cellar Floor

4" Concrete Base, 1-2½-5, Hand Mixed

⅛ bbl. Portland cement at $5.40 per bbl.	$ 0.68
3 lb. hydrated lime at $34 per ton	0.05
1/18 cu. yd. sand at $4.55 per cu. yd.	0.25
⅑ cu. yd. broken stone at $6.25 per cu. yd.	0.70
25 minutes laborer's time, mixing and placing, at $2.00 per hr.	0.83

Cement Finish, 1-to-2

$\frac{1}{10}$ bbl. Portland cement at $5.40 per bbl.	0.54
$\frac{1}{36}$ cu. yd. sand at $4.55 per cu. yd.	0.13
10 minutes laborer's time, mixing and placing at $2.00 per hr.	0.33
$\frac{1}{2}$ hr. finisher's time at $3.25 per hr.	1.63
Total cost per sq. yd.	$ 5.14

DATA ON ASHLAR AND CUT STONE

Cost.—When purchased from the quarry, the stone may be had in rough blocks or in sawed blocks, or it may be cut to finished sizes and shapes. When it is cut to finished shapes, there will be no excess material to pay freight on.

In most cases, however, cut stone is purchased from a local dealer, who buys it in sawed blocks from the quarry and cuts it into the shapes called for by the architect's drawings. The local dealer generally contracts to furnish, cut, deliver, and stack the stone at the building site. Or his contract may include fitting, setting, pointing, and cleaning down.

The cost of stone purchased from a local dealer will vary with the facilities for getting it out of the quarry, with the hardness and nature of the stone, and with the distance that the stone must be hauled to the building. It is difficult, therefore, to give dependable prices. The following approximate prices will help you in estimating:

Good-rock-faced bluestone ashlar, with from 6-in. to 10-in. beds, dressed about 3-in. from the face, will cost, ready for laying, from $1.50 to $1.70 per square foot of face measure. Selected bluestone ashlar will cost from $1.70 to $2.00 per square foot. Regular coursed bluestone ashlar, 12 to 18 in. in length, with from 8-in. to 12-in. beds, will cost about $1.25 per square foot.

Several grades of Indiana limestone are sold in rough quarry blocks at from $0.50 to $3.00 per cubic foot; in quarry blocks sawed on two sides at from $1.00 to $3.50 per cubic foot; and n strips sawed on four sides at from $1.55 to $4.05 per cubic oot. These prices are for carload lots of 36,000 lb. or more.

Indiana limestone that is cut and finished at the quarry in the form of door and window sills, steps, coping, and moldings will cost from $3.00 to $4.00 per cubic foot, crated and placed on cars at the quarry ready for shipment. The purchaser must then pay the freight to the point of delivery.

The cost of transportation from the quarry to the building site can be obtained from the railroad or trucking firm which does the moving. Where the stone is cut to finished shapes, a certain amount of crating is necessary to protect the finished edges.

When the stone is shipped by railroad, it must be taken off the cars and placed on trucks, hauled to the site of the building, and carefully stacked ready for use. The cost of this work will depend on the weignt of the individual stones and on the distance that they must be hauled. For moderate-sized stones, hauled 2 miles, stacked on boards, and protected by boarding, an allowance of $0.75 per cubic foot may be made.

Sometimes the cut stone that is sent to the building site does not fit exactly, and must therefore be trimmed to size before it is set in place. Some cutting will also be required to permit the installation of anchors and dowels. The fitter will also have to cut lewis holes in the stones so that they can be raised by the derricks. Do not overlook these items when making up the estimate.

A stone cutter can cut about 3 sq. ft. of granite per day, 6 sq. ft. of bluestone, and about 8 sq. ft. of Ohio sandstone or Indiana limestone. These figures are for 6-cut patent-hammered work. For rock-face ashlar (beds worked about 3 in. from face, the rest pitched), a workman can dress from 15 to 25 sq. ft. of random ashlar per day, and from 18 to 20 sq. ft. of coursed ashlar. In dressing laminated stone, from two to three times more work in a day can be done on the natural surface than on the edge of layers. In figuring cut stone, an ample allowance should be made for waste, which, on an average, will be 20 per cent.

Ashlar is figured separately from the wall that it faces. The cost of building 100 cu ft. of limestone ashlar 6 in. thick is as follows:

Cost of 100 Cu. Ft. of Limestone Ashlar 6 In. Thick

100 cu. ft. stone at $2 per cu. ft. delivered at job		$200.00
9 cu. ft. mortar		
108 lb. lump lime at $1.40 per 100 lb.	$1.51	
$\frac{1}{10}$ bbl. stainless cement, at $7.60 per bbl.	0.76	
9 cu. ft. sand, at $4.55 per cu. yd.	1.52	
1 hr. laborer's time, mixing, at $2.00 per hr.	2.00	
	$5.79	5.79
12 hr. mason's labor, at $3.25 per hr.		$ 39.00
24 hr. helper's time, at $2.20 per hr.		52.80
6 hr. fitter's time, cutting and trimming		19.50
Total cost of 100 cu. ft.		$317.09

BRICKWORK

MEASUREMENT OF BRICKWORK

The usual method of measuring both face and common brickwork is by the thousand bricks laid in the wall. A customary method of estimating the number of bricks in a piece of brickwork is first to determine the entire area of the face of the wall in square feet, measurements being taken on the outside of the wall, and not on the inside. This is done to offset the extra labor that is required in laying the corners and angles. The number of bricks is computed approximately from these areas, using the number of bricks to the sq. ft. as shown in the accompanying table. The window and door openings in brick walls should always be deducted.

The following is an estimate of the cost of laying common brick per thousand. As previously stated, the prices will vary in different localities at different times. To use these examples, local prices should be substituted for the prices given.

NUMBER OF BRICKS TO THE SURFACE FOOT FOR DIFFERENT SIZES OF BRICKS WITH JOINTS OF VARIOUS THICKNESSES

Size of Brick Inches	Thickness of Joint					
	3/16	¼	5/16	⅜	7/16	½
	Number of Bricks					
7½×3⅜×2⅜	7.31	7.08	6.86	6.65	6.45	6.26
7¾×3¾×2¼	7.44	7.20	6.97	6.75	6.55	6.35
8 ×3¾×2¼*	7.22	6.98	6.76	6.55	6.35	6.17
8 ×4 ×2½	6.55	6.35	6.16	5.98	5.81	5.65
8¼×3¾×2¼	7.00	6.78	6.56	6.36	6.17	5.98
8¼×4 ×2¼	7.00	6.78	6.56	6.36	6.17	5.98
8½×4⅛×2⅜	6.47	6.27	6.08	5.90	5.73	5.57
8½×4⅛×2½	6.17	5.99	5.81	5.64	5.49	5.33
9 ×4½×3	4.92	4.79	4.67	4.55	4.45	4.33

*Standard size adopted by America Society for Testing Materials and the Common Brick Manufacturers' Association of America.

COST OF COMMON BRICKWORK PER THOUSAND BRICK

Using 1-to-3 Lime Mortar Tempered With Cement, Joints ⅜ in. thick, Size of Brick 8 in.×3¾ in.×2¼ in.

1,000 brick	$ 40.00
14 cu. ft. mortar (See rubble masonry)	9.10
8 hr. mason's time at $3.25 per hr.	26.00
10 hr. helper's time at $2.20 per hr.	22.00
Total cost of 1,000 brick laid in wall	$ 97.10

Using Portland Cement Mortar

1,000 brick	$ 40.00
14 cu. ft. mortar (See rubble masonry)	11.90
8 hr. mason's time, at $3.25 per hr.	26.00
10 hr. helper's time, at $2.20 per hr.	22.00
Total cost of 1,000 brick laid in wall	$ 99.90

When hoisting engines and scaffolds are used, these prices will be increased correspondingly.

Cost of Pressed Brickwork Per Thousand Brick

Using 1-to-3 Cement Mortar Tempered With Lime. Joints ¼-in. Struck. Brick 8 in.×3¾ in.×2¼ in. Hoist and Scaffold not included

1,000 brick	$ 60.00
7 cu. ft. mortar (See rubble masonry)	5.95
80 lb. mortar color at $0.10 per lb.	8.00
20 hr. mason's time, at $3.25 per hr.	65.00
15 hr. helper's time, at $2.20 per hr.	33.00
Total cost per 1,000 brick laid in wall	$171.95

CARPENTRY

ESTIMATING QUANTITIES

Board Measure.—Lumber used in framing is measured by the board foot, which is 12 in.×12 in.×1 in. Lumber is sold on the basis of 1,000 ft. board measure. The customary abbreviation for the latter term is B.M., and for thousand is M. Thus, 500 ft., board measure, costing $50 per thousand, would be written: 500 ft. B.M., at $50 per M.

To obtain the number of board feet in any piece of timber, the length in inches may be multiplied by the end area, in square inches, and the result divided by 144. For example, the number of board feet in a floor joist 20 ft. long, 3 in. thick and 10 in. deep, is 240 in. (20×12) multiplied by 30 sq. in. (the end area), or 7,200 sq. in., 1 in. thick; dividing by 144, the result is 50 ft. B.M.

The rule used by most contractors and lumber dealers is as follows:

Rule.—*Multiply the length, in feet, by the thickness and width in inches, and divide the product by 12.*

Thus, a scantling 26 ft. long, 2 in. thick, and 6 in. wide, contains $\frac{26\times2\times6}{12}=26$ ft. B. M. This rule, expressed in a slightly different manner more convenient for mental computation, is as follows:

Rule.—*Divide the product of the width and thickness, in inches, by 12, and multiply the quotient by the length in feet.*

Thus, a 2″×10″ plank, 18 ft. long contains $\frac{2\times10}{12}\times18=30$ ft. B. M.

Studs.—To calculate the number of studs set 16 in. on centers, the following rule may be used:

Rule.—*From the length of the wall or partition, in feet, deduct one-fourth, and to this result add 1. Count the number of returns, or corners, on the plan, and add two studs for each return.*

The reason for adding one is to include the stud at the end, which would otherwise be omitted. The sills, plates, and double studs must be measured separately. For example, five walls or partitions 30 ft. 6 in., 10 ft. 6 in., 9 ft. 6 in., 5 ft. 0 in., and 4 ft. 6 in. would have a total length of 60 ft. If one-quarter, or 15, is deducted from 60, the remainder is 45; add 1 and the result is 46. If there are 4 returns, at 2 studs each, the total number of studs required is $46+8=54$ studs.

As a general rule, when, as is usual, the studs are set at 16-in. centers, 1 stud for each foot in length of walls and partitions will be a sufficient allowance to include sills, plates, and double studs. Thus, if the total length of walls and partitions is 75 ft., 75 studs will be sufficient for sills, double studs, etc. If the studs are set at 12 in. centers, the number required will be equal to the number of feet in the length of the walls and partitions plus one-fourth.

Thus, if the length of the walls and partitions is 72 ft., $72+18$, or 90 studs, will include those required for sills, plates, etc. Some contractors add 10% to these quantities to allow for incidental use of studs, such as for bracing, blocking, scaffolding, etc.

The same principles may be used for calculating the number of joists, rafters, tie-beams, etc.

A good way to estimate bridging is to allow 6¢. apiece, or 12¢. a pair; this will be sufficient to furnish and set a pair made of 2″×3″ spruce or hemlock stuff.

Sheathing.—To calculate sheathing or rough flooring (which is not matched), find the number of feet board measure required to cover the surface, making no deductions for door or window openings, for what is gained in openings is lost in waste. If the sheathing is laid horizontally, only the actual measurement is necessary, but if it is laid diagonally, add 8 to 10% to the actual area. When the sheathing is matched or shiplapped, add from 5 to 15% to the actual area.

In sheathing roofs where many hips, valleys, roof dormers, etc. occur, there will be a great deal of waste material caused by mitering the boards, fitting around the cheeks of dormers and forming saddles behind chimneys. This waste is not readily calculated and must be determined by the actual conditions as well as by the care exercised by the men in utilizing the cuttings. In covering large areas a great deal of material can be saved by ordering the lengths of boards to suit the spacing of the rafters.

Flooring.—In estimating matched flooring, 1 sq. ft. of $\frac{13}{16}$-in. stuff is considered to be 1 ft. B.M. If the flooring boards are 3 in. or more in width, add one-quarter to the actual number of board feet, to allow for waste of material in forming the tongue and groove; if the flooring is less than 3 in. wide, add one-third. Flooring of $1\frac{1}{8}$ in., finished thickness, is considered to be $1\frac{1}{4}$ in. thick; and for calculating it the surface measurement is increased 50%. (This consists of 25% for extra thickness over 1 in., and 25% for waste in tonguing and grooving.) To this amount 5% is added for waste in handling and fitting finished flooring laid perpendicular to the joists. For matched under flooring laid diagonally to the joists, allow 10% for waste. In figuring the area of floors, the openings for stairs, fire-places, etc., should be deducted.

Siding.—Siding is usually measured by the superficial foot. No deduction should be made for ordinary window or door openings, as these usually balance the waste in cutting and

QUANTITIES OF MATERIAL PUT IN PLACE PER HOUR PER MAN

Class of Material	Quantity of Material	Remarks
Studding, 2″×4″ or 2″×6″	50 ft., B.M.	Walls or partitions
Rafters	50 ft., B.M.	Plain gable roofs
Floor joists, 2″×10″, or 3″×12″	56 ft., B.M.	
Sheathing, unmatched	60 ft., B.M.	Laid horizontally
Sheathing, unmatched	50 ft., B.M.	Laid diagonally
Sheathing, matched	45 ft., B.M.	Laid horizontally
Sheathing, matched	35 ft., B.M.	Laid diagonally
Sheathing, roof, unmatched	50 ft., B.M.	Plain gable roof
Sheathing, roof, unmatched	30 ft., B.M.	Much cut up by hips, valleys, dormers, etc.
Sheathing, roof, matched	45 ft., B.M.	Plain roofs
Sheathing, roof, matched	25 ft., B.M.	Cut up
Under-flooring, matched, 5¼″ face	75 ft., B.M.	Perpendicular to joists
Under-flooring, 5¼″ face	60 ft., B.M.	Diagonally to joists
Beveled siding, 6″ wide	50 ft., B.M.	Includes fitting and setting corner boards, water-table, and scaffolding
Beveled siding, 4″ wide	36 ft., B.M.	
Novelty siding	50 ft., B.M.	
Posts and beams over cellar	45 ft., B.M.	
Plaster grounds	30 lin. ft	For base and wainscot, leveled and straightened in good shape
Bridging	15 pairs	Includes cutting and setting

fitting. Careful attention must be given to the allowance for lap. If 6-in. (nominal width, actual width 5⅝ in.) siding, laid with 1-in. lap, is used, add one-quarter to the actual area, in order to obtain the number of sq. ft. of siding required. If 4-in stuff is used, add one-third to the actual area. When no deduction is made for openings, the corner boards and water-tables need not be figured separately.

Cornices.—Cornices may be measured by the running foot, the molded and plain members being taken separately. A good method of figuring cornices is as follows:

Rule.—*Measure the girth, or outline, and allow 3¢ for each inch of girth, per linear foot.*

Quantity of Material Set per Day.—It is impossible to estimate exactly the quantity of material set per day, as it depends on the skill of the artisan, his rapidity of working, the ease or difficulty of the work, besides numerous accidental circumstances. The figures in tables are intended to give an idea of the relative quantities, and not as a standard to be adhered to in all cases. If the quantity of material which a man can set per hour is known, and the price which is paid the mechanic for one hour's work is known, these units can be used for ascertaining the cost of all the work of that kind that is to be done in the building.

Nails.—To calculate the quantity of nails required in executing any portion of the work, the following table will be found useful:

TABLE FOR ESTIMATING QUANTITY OF NAILS

Material	Pounds Required	Kind of Nail
1,000 shingles	5	4d.
1,000 laths, 4 nails to 1 lath	7	3d. fine
1,000 ft., B.M. of beveled siding	18	6d.
1,000 ft., B.M. of sheathing	20	8d.
1,000 ft., B.M. of sheathing	25	8d, or 10d.
1,000 ft., B.M. of flooring	30	8d.
1,000 ft., B.M. of flooring	40	8d. or 10d.
1,000 ft., B.M. of studding	15	8d. or 10d.
1,000 ft., B.M. of studding	25	20d.
1,000 ft., B.M. of furring 1 in. × 2 in.	10	8d. or 10d.
1,000 ft., B.M. $\frac{7}{8}$-in. finished flooring	20	8d. to 10d. finishing
1,000 ft., B.M. 1$\frac{1}{8}$-in. finished flooring	30	8d. or 10d. finishing

ESTIMATING COSTS

The character of the work, which must be determined by the spirit and letter of the specifications, will be the controlling factor in fixing costs. In the case of material, where the requirements are exacting and demand a grade of material that can only be obtained by special selection, an extra rate must always be considered. This is best secured by contracting with the lumber merchants for the supply of the material to accord strictly with the architect's stipulation. The matter of labor, however, is one on which too much care and forethought cannot be expended. What may be considered satisfactory work by one contractor would be considered inferior by another, and this often accounts for the great difference in estimates.

COST OF MISCELLANEOUS ITEMS OF CARPENTRY

Class of Work	Cost
Setting window frames in wooden buildings	$4.00 each
Furring brick walls, 1″×2″ strips, 12-in. centers, including labor and materials....	0.30 per sq. ft.
Furring brick walls, 1″×2″ strips, 16-in. centers, including labor and materials....	0.24 per sq. ft.
Cutting holes and fitting plugs in brick walls	0.60 each
Setting window frames in brick or stone walls, including nails and bracing........	6.00 each
Setting door frames in brick or stone walls, including nails and bracing.............	6.00 each
Furnishing and setting trimmer-arch centers	4.00 each
Arch centers, 3½ ft. span, 8-in. reveal, including supports and wedges............	6.00 each

Cost per Square Foot.—For all classes of materials that enter into the general framing and covering of a building, a close estimate may be made by analyzing the cost per square foot of surface. The cost of labor and materials—studs and sheathing in walls, joists and flooring in floors, etc.—required for a definite area should be closely determined, and this cost, divided by the area in sq. ft., will give the price per sq. ft. If the whole area in sq. ft. of work to be estimated on is multiplied by the figure thus obtained, the result will be the cost of that work.

The flooring example shows how to determine the cost per square foot of flooring, and indicates the general method to be pursued in like cases. The area used in calculation is a square of 100 sq. ft.

COST OF FINISHED FLOOR PER SQUARE

Joists, Y.P., pieces $2'' \times 12'' \times 10' = 160$ ft. B.M. at $100 per M	$ 16.00
Cost of setting, at 56 ft. per hr., 3 hr. carpenter's time, at $2.50 per hr.	7.50
Bridging, 7 set at $0.24 per set	1.68
Rough flooring, laid diagonally, matched, $5\frac{1}{4}''$ face, $100+25+10=135$ ft. B.M. at $200 per M	27.00
Cost of laying, $1\frac{4}{5}$ hr. carpenter's time, at $2.50 per hr.	4.50
Building paper, 100 sq. ft.	2.50
Finished flooring, quarter-sawed oak, $\frac{13}{16} \times 2\frac{1}{4}''$ face, $100+33+5=138$ ft. B.M., at $420 per M	57.96
12 lb. nails at $10 per 100 lb.	1.20
Cost of laying oak flooring, 3 hr. carpenter's time, at $2.50 per hr.	7.50
Scraping and sanding, 4 hr. carpenter's time, at $2.50 per hr.	10.00
Total cost for 100 sq. ft.	$135.84

JOINERY, OR MILLWORK

ESTIMATING QUANTITIES

Millwork includes all the interior and exterior finish put in place after the framing and the exterior sheathing of the building are completed; as, for example, door and window frames, doors, baseboards, paneling, wainscoting, stairs etc. These features are made at the mill and brought to the building ready to be set in place.

Frames.—In taking off door and window frames, describe and state the sizes. Measure the architraves by the running foot, giving the width and thickness, whether plain or molded, and state the number of plinth and corner blocks.

Sash.—State the dimensions of the sash (giving the width first); thickness of material, molded or plain; style of check-rail and sill finish; thickness of muntins, whether plain, single, or double hung; and sizes (giving dimensions in inches) and number of lights. Use standard sizes as much as possible.

Doors.—Describe and state the sizes and thicknesses of all doors; whether the framing is stock-molded, raised-molded, or plain; and the number of panels, whether plain or raised. Use stock sizes wherever possible and suitable.

Blinds.—Describe the size and thickness of blinds, whether paneled or slatted (fixed or movable), molded or plain.

Baseboard and Beam Casings.—Measure the baseboards and beam casings by the running foot, stating the width and thickness of the stuff, and whether molded or plain.

Wainscoting.—Measure the wainscoting by the superficial foot. State the kind of finish, whether paneled or plain, and the style of moldings and panels. Measure the wainscoting cap and base by the running foot.

Stairways.—Stairways are generally taken by the contractor at a unit price per step, including everything complete according to the specifications. In measuring stairways take off the amount of rough material in carriage timbers, and the planed lumber in treads, risers, and strings. Measure balustrades by the lin. foot. Give the size of newels and the style of treatment. Measure spandrel and stairway paneling the same as wainscoting.

Fixtures.—Kitchen dressers may be taken at a fixed price complete, or at a fixed rate per sq. ft., or as dressed lumber, drawers and doors being taken off separately. Wardrobes, bookcases, mantels, and china closets should be treated separately, and a fixed price stated. Porches, exterior balustrades, balconies, porte-cocheres, etc., may be taken at a price per lin. foot, or the actual quantity of material may be measured.

ESTIMATING COSTS OF MILLWORK

Many of the items used in the finish of buildings are made in stock, or standardized, designs which are shown in catalogs together with their prices. These items can be purchased at any time from the mill issuing the catalog. Lumber yards also carry stocks of moldings, door and window frames and trim, and other items of finish which can be purchased readily.

Special designs for exterior and interior finish are also made at mills from details furnished by the owner or builder. The prices of special work are naturally greater than those of stock work.

The mill work is sent to the buildings and is erected by carpenters. The elements of cost are therefore the cost of the product of the mill and the cost of applying at the building.

Moldings are sold by mills and lumber yards by the hundred linear feet. The prices per hundred linear feet vary according to the kind of wood of which the molding is made and the size of the strip of lumber out of which the molding is worked.

Thus, a $\frac{3}{4}'' \times 1\frac{1}{4}''$ molding will be made from a $1'' \times 1\frac{1}{2}''$ strip of lumber. In charging for moldings the price is based on the latter area of coss-section.

A unit used in measuring and pricing moldings is the *molding inch.* A molding inch is equal to a strip 1 in. square and 1 ft. long. A molding of $\frac{3}{4}'' \times 1\frac{1}{4}''$ cross-section will contain $1\frac{1}{2}$ molding inches per foot of length, as it is made from $1'' \times 1\frac{1}{2}''$ material. A molding of $\frac{3}{4}'' \times \frac{3}{4}''$ section is made from $1'' \times 1''$ lumber. Each foot in length will contain 1 molding inch. In 100 lin. ft. there will be 100 molding inches.

The following list gives approximate prices of 100 lin. ft. of moldings made of commonly used wood, for moldings having 1 sq. in. of cross-section. In other words, the prices are for 100 molding inches of moldings. In using this list, the prices may be used for 100 lin. ft. of molding or 100 molding inches.

White pine....	$4.50	Poplar......	$4.00	Yellow pine..	$4.00
Quartered oak	8.00	Plain oak....	7.00	Cypress......	4.00
		Basswood...	4.00		

A $\frac{3}{4}'' \times 4\frac{5}{8}'' \times 100'$ molding made of quartered oak will cost $5 \times \$8$, or $40 per 100 lin. ft.

The cost of applying moldings varies, so that no useful data can be given regarding this cost.

Cost of an Exterior Doorway.—The items that must be considered in estimating the cost of an exterior door frame and door are the frame, consisting of the jambs, head, sill, the exterior trim, the interior trim, and the door.

The cost of an ordinary doorway in a stud wall, formed of $2'' \times 4''$ studs sheathed and covered with bevel siding on the outside, and plastered on the inside, may be analyzed as follows: The sides and head of the frame, including the outside trim, will be white pine, and the sill will be hardwood. The door itself will be oak, 3 ft. × 7 ft. in size, with a glazed panel above and a wood panel below. The interior trim will be white pine. The prices are average prices for the materials as sold by lumber yards or mills:

Side jambs, $1\frac{1}{8}'' \times 5\frac{5}{16}''$ Side casings, $1\frac{1}{8}'' \times 3\frac{3}{4}''$	$ 6.36	
Head jamb, $1\frac{1}{8}'' \times 5\frac{5}{16}''$ Head casing, $1\frac{1}{8}'' \times 3\frac{3}{4}''$ Drip cap $1'' \times 2\frac{1}{2}''$ Hardwood sill, $1\frac{5}{8}'' \times 6\frac{3}{4}''$	4.52	$ 10.88
Inside casing, $\frac{5}{8}'' \times 3\frac{5}{8}''$ (20 lin. ft.)	3.60	
Back band, $1\frac{1}{4}'' \times 1\frac{3}{8}''$ (20 lin. ft.)	2.70	
Plinths, 2 @ 64 cents	1.28	7.58
Door, $3'0'' \times 7'0'' \times 1\frac{3}{4}''$	75.00	75.00
Hardware, lock and 3 butts	15.00	15.00
Setting frame and outside casings, 1 hr. @ $2.50	2.50	
Setting interior casings, 1½ hr. @ $2.50	3.75	
Fitting and hanging door, 2 hr. @ $2.50	5.00	11.25
Total cost of doorway		$119.71

Profit and overhead should be added to this cost.

The item of cost of hardware ($15.00) should appear in the estimate of the hardware of the building. The cost of applying the hardware is usually included in the cost of fitting and hanging the door.

Cost of Double-Hung Window Frame, Windows, and Trim. The cost of a double-hung window frame in a wooden building having walls formed of 2"×4" studs, with sheathing and bevel siding on the outside, and lath and plaster on the inside will be analyzed. A frame having a 2'10"×5'6" sash opening is considered a minimum, or base, size when pricing. In (A) in the following estimate are given the base prices for the parts of such a frame. The prices for larger-sized frames are greater. For each 2 in. or fraction thereof of width above the base size, 5 per cent is added to the base cost of the horizontal parts of the frame. For each 2 in. or fraction thereof of extra height 2½ per cent is added to the cost of the vertical members. In (B) the costs for a 3'4"×6'0" frame are shown. This frame is 3'4"−2'10", or 6 in., wider than the frame in (A), and 3×5 per cent = 15 per cent, must be added to the base prices of the horizontal members The height is increased 6'0"−5'6" or 6 in. and 3×2½ per cent = 7½ per cent must be added to the prices of the vertical members that are affected.

	(A) 2'10"×5'6" Frame		(B) 3'4"×6'0" Frame	
Head jamb and sill	$2.08	(horizontal)	(add 3×5 per cent)	$2.40
Head casing	0.36	(horizontal)	(add 3×5 per cent)	0.42
Drip cap	0.32	(horizontal)	(add 3×5 per cent)	0.38
Side jambs	2.56	(vertical)	(add 3×2½ per cent)	2.76
Side casings	1.14	(vertical)	(add 3×2½ per cent)	1.24
	$6.46			$7.20

The list (B) shows that the larger frame will cost $7.20. The prices are for knocked-down (k.d.) frames with pulleys in place and pockets cut. It will cost $2.50 to put the frame together. To set the frame in place will take one hour's time and cost $2.50.

Double-hung windows also come with frame assembled and sash hung by patented balances for a cost of about $25.00.

The cost of interior trim for a 2'10"×5'6" window frame is about as follows:

Casings, $\frac{3}{4}'' \times 4\frac{5}{8}'' \times 16'0''$	$2.40
Back band, $1\frac{1}{4}'' \times 1\frac{3}{8}'' \times 18'0''$	1.62
Stool, $\frac{3}{4}'' \times 2\frac{7}{8}'' \times 6'0''$	0.48
Apron, $\frac{3}{4}'' \times 3\frac{1}{2}'' \times 6'0''$	0.72
Stops, $\frac{1}{2}'' \times 1\frac{3}{8}'' \times 16'0''$	0.96
	$6.18

It will require about $1\frac{1}{2}$ hr. of a carpenter's time to put the trim in place. At $2.50 per hour this will cost $3.75. The cost of the trim and its application will be $6.18+$3.75=$9.93.

A window of standard size, $2'10'' \times 5'6''$, with the upper sash divided into three lights and glazed with single-strength glass, and the lower sash glazed with one light of double-thick glass will cost about $9.20 with the glass in place. The cost of cast-iron sash weights and cotton sash cord will be about $2.00 for the window. It will require about $\frac{1}{2}$ hr. of the carpenter's time to fit a window (2 sash). This will amount to $1.25. It will require $\frac{1}{2}$ hr. to hang the window and to apply the cord and weights. This will also cost $1.25. The hardware required for a window will consist of a sash lock, and a pair of sash lifts, and will cost about $2.60. It will require about 1 hr. to apply the lock and lifts, and will cost $2.50.

Summary of Costs.—The costs of a complete standard-sized window, including frame, exterior trim, interior trim, window, sash cord and weights, and hardware, will be about as follows:

Frame (k.d.) including exterior trim	$ 6.46
Putting frame together	2.50
Setting frame	2.50
Interior trim	6.18
Placing interior trim	3.75
Window (glazed)	9.20
Sash cord and weights	2.00
Fitting window	1.25
Hanging window (including cord and weights)	1.25
Sash lock and lifts	2.60
Applying lock and lifts	2.50
Total cost	$40.19

Stairs.—The cost of stairs will vary greatly with the character of the design, the materials selected, and the workmanship. A good idea of the cost of the labor and material for an average staircase consisting of a straight run of stairs with a newel at the top and bottom is given in the following table. An open string is included with the balusters dovetailed into the treads. A gooseneck is indicated, also an easing or easement. In the

COST OF STAIRS

(One Straight Run, Open String, Newels, Balusters, Railings, etc., 15 Steps)

	White Pine	Yellow Pine	Plain Oak	Birch
Strings, face, ¾″×11″×16′=16′ B.M.	$ 5.40	$ 5.00	$ 6.70	$ 7.20
Strings, wall, ¾″×11″×16′ molded	5.40	5.00	6.70	7.20
Bottom step		10.75	12.50	12.50
Treads, 1⅛″×11½″×4′×15		37.50	42.50	45.00
Risers, ¾″×7½″×4′×15		17.00	19.50	21.00
Nosings, 1⅛″×1¼″×16″×15		2.55	2.55	2.55
Coves, ¾″×¾″×4′×15=60′ B.M.	1.00	1.00	1.85	1.80
Coves, ¾″×¾″×12′×15=15′ B.M.	0.25	0.25	0.50	0.45
Newels, each, 3½″×3½″×3′8″		4.75	6.00	6.00
Railings, 2¼″×2⅞″×16′		8.00	12.80	12.80
Easement, each		4.20	5.50	5.50
Gooseneck, each		6.75	9.00	9.00
Balusters, 1⅝″×1⅝″×2′8″ (45)		15.00	18.00	18.00
Mitering treads and dovetailing (45)	25.20	25.20	25.20	25.50
		$142.95	$169.30	$174.20
Carpenter's time approx., 24 hr. @ $2.50	60.00	60.00	60.00	60.00
Rough work, carriage, furring, wedging, etc., 3 hr. @ $2.50	7.50	7.50	7.50	7.50
Total cost of stair		$210.45	$236.80	$241.70

Since there are 15 steps, if the entire stair is of plain oak, for instance, the cost per step will be $236.80 ÷ 15 = $15.79.

table the parts are all of stock designs that may be purchased at a mill. Specially designed staircases should be estimated by experienced stairbuilders in order to obtain safe estimates of the costs. The figures given should be verified from the latest mill catalogs when estimates are being made.

In making up an estimate, parts of the stairs that are made of different woods should be combined in one list. Thus, the strings and risers may be of white pine, the rails of birch or oak, the balusters of birch, the treads of oak or birch, etc. Select the prices of the required articles or parts from the proper columns in the table, place them in the list, and add for the total cost of materials. The cost of labor must be added according to experience.

ROOFING

WOODEN SHINGLES

The usual lengths of shingles are 16 and 18 in. Such shingles are sold by the thousand, on the basis of each shingle being 4 in. wide. Usually each shingle is exposed 4 in. Therefore, each shingle will cover 16 sq. in., and 1,000 shingles will cover 111.11 sq. ft. On account of the waste and cutting, however, 1,000 shingles usually are estimated to cover one square of 100 sq. ft., or one *square*, which is the unit by which roofing is measured.

Cost of Wooden Shingles Per Square

1,000 shingles	$18.00
5 lb. galvanized nails at $20.00 per 100 lb.	1.00
4 hr. carpenter's labor at $2.50 per hr.	10.00
2 hr. helper's labor at $2.00 per hr.	4.00
Total cost per square	$33.00

ASPHALT ROOFING

Asphalt shingles are sold by the square, a sufficient number being included to cover one square of 100 sq. ft. The shingles may be separate shingles about 8 in.×12 in., or strip shingles about 32 in.×12 in. The latter cover the space of four individual shingles.

COST OF ASPHALT SHINGLES PER SQUARE

Using Individual Shingles 8 in.×12 in., Laid 4 in. to Weather

1 square (450) shingles	$12.00
4 lb. galvanized nails at $20.00 per 100 lb.	0.80
4½ hr. carpenter's time at $2.50 per hr.	11.25
2 hr. helper's time at $2.00 per hr.	4.00
Total cost per square	$28.05

Using Strip Shingles 32 in.×12 in., Laid 4 in. to Weather

1 square (113) shingles	$10.00
2 lb. galvanized nails at $20.00 per 100 lb.	0.40
3½ hr. carpenter's time, at $2.50 per hr.	8.75
2½ hr. helper's time, at $2.00 per hr.	5.00
Total cost per square	$24.15

Asphalt roofing is sometimes made in rolls 32 in. wide, each roll containing 1 square of roofing. This roofing is known as *roll roofing*, or *prepared roofing*.

COST OF ROLL ROOFING PER SQUARE

1 roll (100 sq. ft.) roofing	$3.50
1 lb. galvanized nails	0.20
1 hr. carpenter's time, at $2.50 per hr.	2.50
1 hr. helper's time, at $2.00 per hr.	2.00
Total cost per square	$8.20

ASBESTOS SHINGLES

Thin plates of asbestos and Portland cement are used for roofing. There are two general types. One kind includes the French and diagonal, or honeycomb, patterns, and the other the

American or straight-laid pattern. The latter resemble shingles or slates, and are laid in the same manner.

COST OF ASBESTOS SHINGLE ROOFING PER SQUARE

French and Diagonal Types, Using Plates 16 in.×16 in.

1 square asbestos shingles	$20.00
1 square 40-lb. felt	1.50
2 lb. copper nails, at $60.00 per 100 lb.	1.20
90 storm nails, copper, at 1¢ each	0.90
3 hr. slater's time, at $2.50 per hr.	7.50
2 hr. helper's time, at $2.00 per hr.	4.00
Total cost per square	$34.20

American Type Shingles 8 in.×16 in., Laid 6½ in. to Weather

1 square asbestos shingles	$40.00
1 square 40-lb. felt	1.50
3 lb. copper nails, at $60.00 per 100 lb.	1.80
2 hr. slater's time, at $2.50 per hr.	5.00
4 hr. helper's time, at $2.00 per hr.	8.00
Total cost per square	$56.30

SLATE ROOFING

COST OF SLATE ROOFING PER SQUARE

Using Bangor Slate 8 in.×16 in. and $\frac{3}{16}$ in. Thick, Laid With 3 in. Lap, 6½ in. to the Weather

1 square slate, including freight and hauling	$30.00
3 lb. copper nails at $60.00 per 100 lb.	1.80
1 square slater's felt	1.50
5 hr. slater's time, at $2.50 per hr.	12.50
5 hr. helper's time, at $2.00 per hr.	10.00
Total cost per square	$54.30

Vermont slate, 8 in.×16 in., and $\frac{3}{16}$ in. thick, laid with 3-in. lap, will cost $3 per square more, or $57.30.

This estimate is for ordinary roofs. If the roof is steep, or cut up with hills or valleys, the cost will be increased from 5 to 20 per cent.

TILE ROOFING

Tile roofing is made in a number of styles. In most of these styles special tiles or shapes must be cut for such places as the eaves, valleys, hips, ridges, etc. All special work must be carefully measured and the dimensions sent to the tile manufacturer both for estimating and for manufacturing the tile. For this reason the cost of tile roofing will vary with the design of the roof.

A typical style of tile is known as the *Spanish*, or S *tile*, on account of the shape of the surface. For an ordinary roof the cost per square will be about as here shown:

COST OF SPANISH TILE ROOFING PER SQUARE

Using Plain Tile, With Average Number of Hips and Valleys

1 square tile	$60.00
1 square 40-lb felt	1.50
4 lb. 5d. copper nails at $60.00 per 100 lb.	2.40
8 hr. tile layer's time, at $2.50 per hr.	20.00
8 hr. helper's time, at $2.00 per hr.	16.00
Total cost per square	$99.90

If green-surfaced tile is used, the price for the tile will be increased $5.00 per square. If glazed green tile is used, the price will be increased $20.00 per square.

TIN ROOFING

Tin roofing is estimated by the square of 100 sq. ft. Hips and valleys are measured 1 ft. wider their entire length to compensate for increased labor and waste of material in cutting and laying. A sheet of tin plate 14 in. × 20 in. with ½ in. edges turned all around measures 13 in. × 19 in., or 247 sq. in. Tin is sold by the box, each box containing 112 sheets 20 in. × 28 in. or the equivalent in sheets one-half the size, (14 in.×20 in). or one quarter the size, (10 in.×14 in.).

COST OF TIN ROOFING PER SQUARE

Using Sheets 14 in.×20 in. Flat Seam

63 sheets 14 in.×20 in. at $26.00 per box	$14.63
7½ lb. solder at 60¢ per lb.	4.50
Charcoal and rosin	1.00
3 lb. nails at $25.00 per 100 lb.	0.75
4 hr. tinner's time, at $2.50 per hr.	10.00
4 hr. helper's time, at $2.00 per hr.	8.00
Painting (both sides)	7.00
Total cost per square	$45.88

When sheets 10 in.×14 in. are used, the cost of material and labor will be increased about $8.00 to $10.00 per square, or about 20 per cent.

CANVAS ROOFING

COST OF CANVAS ROOFING PER SQUARE

Using Canvas 36 in. Wide

Canvas roofing is figured by the square, including the labor of laying and painting.

12⅔ yd. canvas, at $2.00 per yd.	$24.45
2 lb copper tacks at 50¢ per lb.	1.00
1 gal. paint (2 coats)	6.00
4 hr. mechanic's time laying and painting at $2.50 per hr.	10.00
Total cost per square	$41.45

The cost per square (100 sq. ft.) of composition roofing will depend on the number of thicknesses of felt and the quantity of pitch used per square. It will also be affected by the height of the roof from the ground, and the number of objects, such as skylights and chimneys, that project through the roof.

Composition roofs are made 3-ply, 4-ply, and 5-ply. A good 4-ply roof on boards consists of 1 ply of unsaturated felt, 4 layers of saturated felt cemented together with pitch or tar, and covered with a coat of pitch in which is embedded a layer of crushed stone or gravel, and will cost about as follows:

Felt, unsaturated, 1 ply, 110 sq. ft. @ $0.75 per 100 sq. ft.	$ 0.83
Felt, saturated, 4 plies, 440 sq. ft. @ $1.50 per 100 sq. ft.	6.60
Tar or pitch, 185 lb. @ $2.00 per 100 lb.	3.70
Nails and caps, @ $0.25 per 100 sq. ft.	0.25
Gravel, 400 lb. @ $5.00 per ton	1.00
Roofer, 1 hr. @ $2.50 per hr.	2.50
Helper, 1 hr. @ $2.00 per hr.	2.00
Total cost per square	$16.88

A 4-ply roof on concrete slabs will cost about $1.00 per square more, or about $18.88. A 3-ply roof on boards will cost about $1.00 less per square than a 4-ply roof. A 5-ply roof will cost $2.00 more per square than a 4-ply roof. A 5-ply "Barrett Specification" roof will cost about $20.00 per square.

LATHING, PLASTERING, AND STUCCO

Measurement.—Lathing and plastering are measured by the square yard. Measurements for walls are taken from floor to ceiling, and for ceilings from wall to wall. Where the walls contain one or more angles between the floor and ceiling line—for example, under pitched roofs—the measurement for the ceiling is taken from wall to wall at the ceiling line; and the measurement for the height of the wall is taken from floor to highest point of ceiling.

In plastering, openings are measured between grounds. Many estimators do not deduct for the usual door and window openings. Other estimators do not deduct for openings of 2 ft. or less in width, but deduct one-half of the contents for openings 2 ft. or more in width. The latter procedure will be followed here. An exception is made for store-front openings, for which the entire contents are deducted. The contractor is allowed 1′6″ for each jamb by the height of the opening when the return or reveal is less than 1′. No openings are deducted from solid- or hollow-metal lath-and-plaster partitions. Nor are deductions made for openings in suspended ceilings containing less than 100 sq. ft., where furring is carried around such openings by the plasterer. No openings are deducted from cement wainscot or base.

For each external and internal angle on all beams or girders projecting below the ceiling line, add 1 ft. of width by the total length, to the actual area. All corner angles of more or less than 90° (degrees), beads, bullnoses, quirks, rule joints, and moldings are measured in linear feet on their longest extension, and 1′ is added for each stop and miter.

The length of cornices is measured by the total length of the walls. Plain cornices of 1 ft. or less in girth are measured on the walls by the linear foot. Plain cornices exceeding 1 ft. in girth are measured either by the square foot of exposed surface or by the linear foot; the girth of each cornice is stated. Add 1 lin. ft. for each stop or internal miter, and 3 lin. ft. for each external miter. Enriched cornices (cast work) are estimated by the linear foot for each enrichment.

Arches, corbels, brackets, rings, centerpieces, pilasters, columns, capitals, bases, rosettes, bosses, pendants, and niches are estimated by the piece. Ceiling frieze plates are estimated by the square foot. All plain plastered columns are measured by the linear foot, or by the square yard, found by multiplying the girth by the height. Cement wainscot is measured by the square foot or square yard. Cement base is measured by the linear foot. Circular or elliptical work on a small radius is estimated at twice the rate of straight work.

Grounds for various classes of plastering, unless specified otherwise, are as follows:

For 2 or 3 coats of gypsum-cement plaster on gypsum block	½ in.
For 2 or 3 coats of plaster on brick or tile	⅝ in.
For 3 coats of plaster on metal lath	¾ in.
For 2 or 3 coats of plaster on gypsum lath or plasterboard	⅞ in.

Where metal lath is mentioned, reference is to all wire or metal lath. Wood lath is seldom used today, and the use of wood lath is, therefore, not dealt with in this text.

Lathing and plastering are estimated by the unit of 100 sq. yd. (square yards).

Scaffolding is the property of the plaster contractor, and is included in the overhead costs. Scaffolding is placed and removed by the plasterer's helper as part of his regular work.

Channels and Studs.—Cold-rolled channels are used as supports for metal lath for ceiling work and partitions. They are supplied in standard sizes and weights. The ¾ in. size has a ¾ in. face and is ½ in. deep. It weighs 300 lb. per thousand feet and is packed 20 pieces to the bundle. The 1½ in. size is 1½ in. wide and approximately ½ in. deep. It weighs 475 lb. per thousand feet and is packed 10 pieces to the bundle. The price of steel fluctuates and for each new estimate the cost of the required amount of channels should be obtained from the jobber.

Where an unusual degree of fire resistance is required, hollow metal studs are used for hollow partitions. These studs are manufactured by several producers of metal lath in 2½-in., 3¼-in., 4-in., and 6-in. widths. They are designed to permit the enclosure of conduits, pipes, and other concealed work. The framework at the top and bottom of the partitions consists of channel tracks which are anchored to the ceiling and floor.

The cost of 100 sq. yd. of hollow-metal-stud partition, with studs on 24 in. centers, is determined as follows:

Top track	105 lin. ft.	@ $0.07 =	$ 7.35
Bottom track	105 lin. tt.	@ .07 =	7.35
Studs 9 ft. long and 24 in. on centers, 51	490 lin. ft.	@ .07 =	34.30
Ribbed lath	214 sq. yd.	@ .50 =	107.00
Tie wire	10 lb.	@ 0.22 =	2.20
Lather	32 hr.	@ 3.25 =	104.00
Total cost for 100 sq. yd.			$262.20

Allowance made for framing openings.

Lath.—Gypsum lath is furnished in thicknesses of either ⅜ in. or ½ in. The usual gypsum lath is 16″×48″, which will fit the common stud and joist spacings. The cost of applying gypsum lath to wood studs and joists will be about as follows:

Gypsum lath, ⅜ in. thick	100 sq. yd.	@ $0.33 =	$33.00
Nails, 1⅛ in., 13-gage flathead blued	7 lb.	@ 0.15 =	1.05
Lather	8 hr.	@ 3.25 =	26.00
Total cost per 100 sq. yd.			$60.05

Gypsum lath backed with aluminum foil costs about $0.02 a square foot more than plain lath.

When metal lath nailed or stapled to wood studs and wood ceiling joists is used as a plaster base, enough lath is needed to equal the actual areas to be covered plus from 4 to 7 per cent for lapping edges and ends. Depending on the areas involved, a lather will apply 90 to 110 sq. yd. of lath in an 8-hr. day. The cost of 100 sq. yd. of metal lath applied on wood studs and joists, allowing 5 per cent excess for lapping, will be used as follows:

Metal lath	105 sq. yd.	@ $0.45 =	$47.25
Nails or staples	15 lb.	@ 0.20 =	3.00
Lacing wire	1 lb.	@ 0.22 =	0.22
Labor applying	10 hr.	@ 3.25 =	32.50
Total cost per 100 sq. yd.			$82.97

The metal lath used in this estimate weighs 3.4 lb. per square yard.

To apply a metal-lath ceiling on metal furring, the lath must be tied to the furring. The cost of 100 sq. yd. of metal lathing suspended from metal furring, allowing 5 per cent excess for lapping, will be about as follows:

Metal lath	105 sq. yd.	@ $0.45 =	$47.25
Tie wire	5 lb.	@ 0.22 =	1.10
Labor	10 hr.	@ 3.25 =	32.50
Total cost of 100 sq. yd.			$80.85

The metal furring that will be required in an average situation to support 100 sq. yd. of suspended metal-lath ceiling will cost about as follows:

Metal hangers, ¼-in. rods	55 lb.	@ $0.10 =	$ 5.50
2-in. channels	550 lb.	@ 0.10 =	55.00
¾-in. channels	380 lb.	@ 0.10 =	38.00
Wire	4½ lb.	@ 0.22 =	0.99
Labor	27 hr.	@ 3.25 =	87.75
Total cost of 100 sq. yd.			$187.24

Corner beads are usually applied to the projecting corners of walls. A good corner bead will cost about $0.08 per linear foot, and setting it plumb and true will cost about $0.10 a foot.

Ribbed lath, if used, will cost about $0.50 per square yard. This material may be used on heavy suspended ceilings in place of ordinary metal lath. The cost of 100 sq. yd. of ⅜ in. ribbed lath, allowing 5 per cent for lapping, will be about as follows:

Ribbed lath, ⅜ in.	105 sq. yd.	@ $0.50 =	$ 52.50
Tie wire	5 lb.	@ 0.22 =	1.10
Labor	18 hr.	@ 3.25 =	58.50
Total cost per 100 sq. yd.			$112.10

Two-Coat Gypsum Plaster.—The cost of two-coat plastering, using gypsum plaster, white finish, on brick or structural-clay-tile walls with ⅝-in. grounds, ordinary grade of work, per 100 sq. yd. is as follows:

Base coat—1:3

Gypsum plaster	11 bags (1,100 lb.)	@ $1.50 =	$16.50	
Sand	1⅓ cu. yd.	@ 4.55 =	6.07	
Plasterer	9 hr.	@ 3.25 =	29.25	
Laborer	6 hr.	@ 2.20 =	13.20	$ 65.02

Finishing coat, white finish

Finishing hydrated lime	7 bags	@ $0.85 =	$ 5.95	
Plaster, gaging	1⅖ bags	@ 1.30 =	1.82	
Plasterer	8 hr.	@ 3.25 =	26.00	
Laborer	4 hr.	@ 2.20 =	8.80	42.57

Total cost, base and finish, per 100 sq. yd. $107.59

If the brick or terra-cotta wall is very uneven, add 10 to 15 per cent to the price of the base coat.

The cost of two-coat plastering, gypsum plaster, sand finish, on brick or terra-cotta walls, ⅝-in. grounds, per 100 sq. yd. is as follows:

Base coat (as found earlier) $ 65.02

Finishing coat, sand finish

Gypsum plaster	2 bags	@ $1.50 =	$ 3.00	
Sand	⅐ cu. yd.	@ 4.55 =	0.65	
Plasterer	8½ hr.	@ 3.25 =	27.63	
Laborer	4 hr.	@ 2.20 =	8.80	40.08

Total cost of base and finishing coats per 100 sq. yd. $105.10

The cost of two-coat gypsum plaster on gypsum lath, white finish, ¾-in. grounds, per 100 sq. yd. is as follows:

Base coat

Gypsum plaster	10 bags (1,000 lb.)	@ $1.50 =	$15.00	
Sand	1 cu. yd.	@ 4.55 =	4.55	
Plasterer	8 hr.	@ 3.25 =	26.00	
Laborer	6 hr.	@ 2.20 =	13.20	$ 58.75

Finishing coat, white finish (as found earlier) 42.57

Total cost, base and finish coats, per 100 sq. yd. $101.32

Three-Coat Gypsum Plaster.—The cost of three-coat gypsum plaster on metal lath, ⅝-in. grounds, white finish, per 100 sq. yd. is as follows:

Scratch coat—1:2				
Fibered gypsum plaster	8 bags	@ $1.50 =	$12.00	
Sand	⅔ cu. yd.	@ 4.55 =	3.04	
Plasterer	5 hr.	@ 3.25 =	16.25	
Laborer	5 hr.	@ 2.20 =	11.00	$ 42.29
Brown coat—1:3				
Gypsum plaster	12 bags	@ $1.50 =	$18.00	
Sand	1⅓ cu. yd.	@ 4.55 =	6.07	
Plasterer	9 hr.	@ 3.25 =	29.25	
Laborer	6 hr.	@ 2.20 =	13.20	66.52
Finishing coat, white finish (as found earlier)				42.57
Cost per 100 sq. yd.				$151.38

Three-Coat Plaster Using Light-Weight Aggregate.—The cost of three-coat plastering on metal lath, using gypsum plaster, perlite or vermiculite aggregate, white finish, per 100 sq. yd. is as follows:

Scratch coat—1:2				
Gypsum plaster	11 bags	@ $1.50 =	$16.50	
Aggregate	22 cu. ft.	@ 0.40 =	8.80	
Plasterer	5 hr.	@ 3.25 =	16.25	
Laborer	5 hr.	@ 2.20 =	11.00	$ 52.55
Brown coat—1:3				
Gypsum plaster	13 bags	@ $1.50 =	$19.50	
Aggregate	39 cu. ft.	@ 0.40 =	15.60	
Plasterer	8 hr.	@ 3.25 =	26.00	
Laborer	6 hr.	@ 2.20 =	13.20	74.30
Finish white coat (as found earlier)				42.57
Total cost, base and finish coats, per 100 sq. yd.				$169.42

Keene's Cement Finish.—In such locations as kitchens, bathrooms, laundries, and toilet rooms where Keene's cement is used for a finish white coat over a gypsum-cement or portland-cement brown coat, the cost per 100 sq. yd. would be about as follows:

Keene's cement	4 bags (400 lb.)	@ $3.20 =	$12.80
Hydrated lime	2 bags (100 lb.)	@ 0.85 =	1.70
Plasterer	12 hr.	@ 3.25 =	39.00
Laborer	6 hr.	@ 2.20 =	13.20
Cost of finishing coat, per 100 sq. yd.			$66.70

For ruling Keene's-cement wainscotings to imitate tiling, per 100 sq. yd., add approximately 12 hr. at $3.25 an hour, or $39.00, to the plasterer's time of $39.00.

Ornamental Plastering.—Plaster cornices less than 12 in. in girth are usually measured by the linear foot. For cornices over 12 in. in girth, surface measurement is used. Enriched cornice members, such as carved moldings, are measured by the linear foot for each row of enrichment. For internal angles or miters, add 1 ft. to the length of the cornice; and for external angles, add 3 ft. to the length. Sections of cornices less than 12 in. in length are measured as 12 in. Add one-half of the length for raking cornices. For octagonal, hexagonal, and similar cornices less than 10 ft. in single stretches, measure one and one-half times the length.

This method takes care of the extra labor, but results in the listing of more material than is necessary. This must be considered when materials are ordered from the estimating lists.

Column and pilaster capitals, frieze enrichments, and work of this character—all of which require artistic treatment—are either made to conform to the models furnished by the architect, or modeled from the architect's designs. If they are modeled from the architect's designs, the models are submitted to the architect for approval. Models are expensive and prices are usually obtained from specialists in this work. Where metal lath and furring are required for ornamental plaster, the cost of this work must be included in the estimate.

Stucco.—Exterior plaster is commonly known as stucco. Most of the stucco used today is portland-cement stucco consisting of portland cement, sand, and a small percentage of lime. Prepared stucco is factory-mixed by the manufacturer in the proper proportions to give the required textured finishes and colors.

The cost of three-coat portland-cement stucco on metal lath over wood framing, float finish, per 100 sq. yd. is as follows:

Scratch coat—1:3				
Portland cement	8 bags	@ $1.35 =	$10.80	
Hydrated lime	$1\frac{2}{5}$ bags	@ 0.85 =	1.19	
Sand	$\frac{8}{9}$ cu. yd.	@ 4.55 =	4.04	
Plasterer	6 hr.	@ 3.25 =	19.50	
Laborer	6 hr.	@ 2.20 =	13.20	$ 48.73
Brown coat—1:3				
Portland cement	16 bags	@ $1.35 =	$21.60	
Hydrated lime	$2\frac{1}{2}$ bags	@ 0.85 =	2.13	
Sand	$1\frac{7}{9}$ cu. yd.	@ 4.55 =	8.09	
Plasterer	12 hr.	@ 3.25 =	39.00	
Laborer	8 hr.	@ 2.20 =	17.60	88.42
Float finish coat				
Waterproof portland cement	5 bags	@ 1.35 =	6.75	
Sand	$\frac{5}{9}$ cu. yd.	@ 4.55 =	2.53	
Plasterer	12 hr.	@ 3.25 =	39.00	
Laborer	6 hr.	@ 2.20 =	13.20	61.48
Total cost per 100 sq. yd.				$198.63

If a smooth, troweled finish is required, add 4 hr. to the plasterer's time. If a textured finish coat is called for, add 2 hr. to the plasterer's time.

The cost of three-coat colored cement stucco on metal lath over wood framing, float finish, per 100 sq. yd., is about as follows:

Scratch coat (as found earlier)				$ 48.73
Brown coat (as found earlier)				88.42
Float finish coat				
Waterproof white cement	2 bags	@ $3.00	= $ 6.00	
Hydrated lime	2 bags	@ 0.85	= 1.70	
White sand	2/9 cu. yd.	@ 6.00	= 1.33	
Color	18 lb.	@ 0.30	= 5.40	
Plasterer	12 hr.	@ 3.25	= 39.00	
Laborer	6 hr.	@ 2.20	= 13.20	66.63
Total cost per 100 sq. yd.				$203.78

The cost of three-coat portland-cement stucco, float finish, over a brick, clay-tile, or concrete-block surface, per 100 sq. yd., will be as follows:

Scratch coat—1:3				
Portland cement	6 bags	@ $1.35	= $ 8.10	
Hydrated lime	1 bag	@ 0.85	= 0.85	
Sand	⅔ cu. yd.	@ 4.55	= 3.03	
Plasterer	6 hr.	@ 3.25	= 19.50	
Laborer	5 hr.	@ 2.20	= 11.00	$ 42.48
Brown coat—1:3				
Portland cement	10 bags	@ $1.35	= $13.50	
Hydrated lime	1½ bags	@ 0.85	= 1.28	
Sand	1⅑ cu. yd.	@ 4.55	= 5.06	
Plasterer	10 hr.	@ 3.25	= 32.50	
Laborer	6 hr.	@ 2.20	= 13.20	65.54
Float finish coat				
Waterproof portland cement	5 bags	@ $1.35	= $ 6.75	
Sand	5/9 cu. yd.	@ 4.55	= 2.53	
Plasterer	12 hr.	@ 3.25	= 39.00	
Laborer	6 hr.	@ 2.20	= 13.20	61.48
Total cost per 100 sq. yd.				$169.50

A dry, rough-cast finish is obtained by applying a ¼-in. finish coat over the brown coat. This is brought to a straight, smooth finish, and dry aggregate is thrown onto the finish coat. To determine the cost of three-coat cement stucco with rough-cast finish coat on either metal lath or masonry, take the costs of the scratch and brown coats as found earlier, and add the following for the finish coat:

Waterproof portland cement	4	bags	@	$ 1.35 =	$ 5.40
Sand	⁴⁄₉	cu. yd.	@	4.55 =	2.02
Aggregate (medium size)	⅓	cu. yd.	@	66.00 =	22.00
Plasterer	20	hr.	@	3.25 =	65.00
Laborer	10	hr.	@	2.20 =	22.00
Total cost of finish coat per 100 sq. yd.					$116.42

Special Stucco Finishes.—A prepared stucco is available and may be used to obtain various colors and rough-textured finishes, such as Italian travertine, Spanish texture, California mission finish, and colonial finish. The scratch and brown coats of portland-cement mortar are applied in the usual manner for the kind of support being used. The final coat is then applied and finished by the manipulation of trowel, brush, sponge, or scraper. The cost of 100 sq. yd. of scratch coat and brown coat are found as shown earlier. The cost of 100 sq. yd. of finish coat is about as follows:

Special stucco material	1,250 lb.	@	$0.03 =	$37.50
Plasterer	12 hr.	@	3.25 =	39.00
Laborer	6 hr.	@	2.20 =	13.20
Cost of 100 sq. yd. of special stucco finish				$89.70

PAINTING AND PAPERING

PAINTING

Method of Measuring.—Painting is measured by the superficial yard or by the square of 100 sq. ft., allowing additions to the actual surface to compensate for the difficulty of covering deep quirks of moldings, for carved and enriched surfaces, etc.

Ordinary door and window openings are usually measured solid, on account of the extra time taken in working around them, cutting in the window sash, etc. Porch and stair balustrades, iron railings, and work having numerous thin strips are also figured solid, for a like reason. Additional charge is frequently made for work that is distant from the ground as cornices, dormers, etc., and also where the work is difficult of access.

Charges are usually made for each coat of paint put on, at a certain price per yd. or square.

Graining and marbling (imitations of wood and stone) and varnishing are rated at prices higher than plain work.

Capitals and columns and other ornamental work which is difficult to measure, should be enumerated, and a clear description of the amount of work on them should be given.

Quantities.—If ready-mixed paint or paint mixed at the building is used, 1 gal. will cover 200 to 250 sq. ft. of wood surface, two coats. For covering metallic surfaces, 1 gal. will cover from 300 to 350 sq. ft., two coats. The weight per gal. of paint ready to apply varies considerably, but, on an average, may be taken at about 16 lb.

Miscellaneous Data.—Prepared shingle stains will cover about 150 sq. ft. of surface per gal., one coat, if applied with a brush; or this quantity will be sufficient for dipping about 300 smooth shingles. Rough-sawed shingles will require about 50% more stain than smooth ones.

Five pounds of cold-water paint mixed with 1 gal. of water will cover 300 to 350 sq. ft. for the first coat on wood, according to surface condition, and about 250 sq. ft. on brick or stone surfaces.

One gal. of liquid pigment filler, hard oil finish, or varnish, will generally cover from 300 to 400 sq. ft. of surface, according to the nature of the wood and finish. Ten pounds of paste wood filler will cover about 300 sq. ft. of surface.

For glazing 100 lights of glass up to 20 in.×28 in., about 100 lb. of putty will be required.

The following table gives the proportions of materials to use for paint to be used on wood:

PROPORTIONS OF MATERIALS

Coat	Lead Pounds	Raw Oil Gallons	Japan Drier Pints	Turpentine Gallons
Priming	100	4 to 6	1 to 1½	1½ to 2½
Second	100	1½ to 2	1	1 to 2½
Third	100	3 to 3½	1	....

One gal. of varnish weighs from 8 to 9 lb.; turpentine, about 7 lb.; and boiled or raw linseed oil, about 8 lb.

For puttying, about 5 lb. will be sufficient for 100 sq. yd. of interior or exterior work.

For sizing, about ½ lb. of glue to 1 gal. of water is used. This mixture will cover from 800 to 1,000 sq. ft. of surface.

Cost of Painting Exterior Work.—The following figures represent fair average prices for material and labor required for 100 sq. ft. of surface on various classes of work:

EXTERIOR PAINTING ON WOOD

	Materials	Labor	Total
Priming coat, new work	$1.38	$3.12	$5.00
Succeeding coats, 1 color	1.25	2.50	3.75

EXTERIOR PAINTING ON BRICK WORK

	Materials	Labor	Total
Priming coat	$2.58	$2.50	$5.08
Additional coats, 1 color	1.41	1.67	3.08

EXTERIOR PAINTING ON METAL WORK

	Materials	Labor	Total
1 coat red lead and oil, smooth surfaces	$1.55	$1.25	$2.80
1 coat red lead and oil, structural surfaces	2.15	1.50	3.65
Additional coats, red lead and oil, each	2.15	1.75	3.90

SHINGLE STAIN

	Materials	Labor	Total
Dipping, per 1,000 (to cover 1 square)	$12.00	$1.25	$13.25
1 brush coat on roof	3.00	1.63	4.63
Additional brush coats, each	2.75	1.25	4.00

Cost of Finishing Interior Woodwork.—The cost of painting interior woodwork per 100 sq. ft. will be as follows:

	Materials	Labor	Total
Priming, lead, and oil	$0.95	$1.88	$2.83
Additional coats, 1 color	1.35	2.25	3.60
1 coat enamel	1.50	2.50	4.00

HARDWOOD FINISH

	Materials	Labor	Total
1 coat paste filler, and removing surplus	$0.78	$1.88	$2.66
1 coat liquid filler	.78	1.88	2.66
1 coat shellac	.88	1.25	2.13
1 coat varnish	1.86	1.25	3.11
Sanding between varnish coats	.25	1.25	1.50
Rubbing to dull finish	.25	2.15	2.40
1 coat wax	.67	2.50	3.17
1 coat stain	1.26	1.25	2.51

Cost of Finishing Hardwood Floors.—The cost of finishing hardwood floors per 100 sq. ft. is estimated as follows:

	Materials	Labor	Total
Paste filler, applying and removing surplus	$0.78	$1.88	$2.66
1 coat shellac	0.88	1.25	2.13
1 coat wax	0.67	0.75	1.42
1 coat varnish	1.86	1.88	3.74
Sanding between varnish coats	0.25	1.25	1.50
Rubbing to egg-shell finish	0.25	2.50	2.75

Cost of Finishing Plastered Walls.—The cost of finishing plastered walls per 100 sq. ft. will be as follows:

	Materials	Labor	Total
1 coat of calcimine, stippled	$0.15	$0.80	$0.95
Washing walls and removing old finish		.54	.54
1 coat glue size	.05	.24	.29
1 coat varnish size	.05	.55	.60
1 coat calcimine, smooth surfaces	.12	.48	.60
1 coat calcimine, sand finish surfaces	.15	.55	.70

PAPERING

Papering is usually figured by the roll, put on the wall. The paper is generally 18 in. wide, although some styles are made in 30- and 36-in. widths. In length the paper is either in 8-yd., or single, rolls, or in 16-yd., or double, rolls. In estimating the number of rolls required, allowance should be made for waste due to matching the pattern. The amount required is determined approximately as follows: Divide the perimeter of the room by 1½ (the width of the roll in feet); the result will be the number of strips required. Find the number of strips that can be cut from a roll, and divide the first result by the second; the quotient will be the number of rolls required. One-half the area of all openings more than 20 sq. ft. in area should be deducted, in order to allow for cutting and fitting at such places. Add about 15% to the area to allow for waste in matching.

The cost of wall paper is extremely variable, ranging from 15¢ to $6, the highest prices being charged for double rolls; the average cost is probably 50¢ to 75¢ per roll for ordinary houses. A border 9 in. wide costs 15¢ per yd., and one 4 in. wide costs 8¢. Paperhanging costs from $1.25 to $2.50, per roll with strips butted, the lower figure being for the usual grade of work and the higher for the double rolls. With lapped strips, the cost is less, being from 75¢ to $1.50 per roll.

MISCELLANEOUS ESTIMATES

Plumbing.—The prices of plumbing fixtures will depend on the type of equipment designated by the owner. Bath tubs range from $85 up, lavatories from $30, water closets from $60, kitchen sinks from $60, and laundry trays from $25 for a single tub. Kitchen sinks are made in a great variety of styles and sizes from the small porcelain-enameled cast-iron sink to the large cabinet sinks with double-drainboard construction with two basins or one basin with garbage disposal and a dishwasher in place of the other basin. A hot-water tank costs about $50 and a gas heater to heat the water about $75.

The average price for fixtures of suitable quality for a seven- to nine-room house with one bath will be about $500. Installation would cost about $900, or a total of $1400 for the plumbing.

Electric Wiring.—The cost of wiring an ordinary house will depend upon the kind of wiring used. Pipe conduit to every outlet will cost about $15 per outlet, while flexible BX will cost about $13 per outlet. Electric fixtures will cost about $300 for an ordinary house.

Heating.—The cost of hot-air heating installation is approximately from 4 to 6% of the total cost of a house; the cost of steam heating is about 7 to 9%; and the cost of hot-water heating is about 9 to 11%. In hot-air heating, about one-fourth of the cost is for labor. In steam heating and hot-water heating about one-sixth of the cost is for labor.

Hardware.—The cost of hardware is best estimated by making an itemized list from the plans. The cost of hardware depends entirely on the quality of the hardware desired, and the best way to estimate on it is, after making the schedule, to select suitable designs and submit the list to a hardware dealer. An approximate estimate for ordinary buildings is 1½% of the cost of the building. From 15 to 20% of the cost of the hardware will pay for putting it in place.

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